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Economic and Mechanical Problems Vie for Notice at Production Meeting

William Howard McCoy

Manager, Experimental Production Machine Shop, General Motors Corp., is vice-president of the S.A.E. representing the Production Activity under whose auspices was conducted the general production meeting in Detroit, Oct. 10 and 11.

A BATTLE over factory equipment buying policies, strong emphasis on the need for closer study of cutting oil problems, exposition of methods of meeting automotive balancing problems, detailed description of practical production experience with surface broaching and a stirring call to production men for maximum cooperation with the industry's selling forces were outstanding features of the general Production Meeting of the Society held Oct. 10 and 11 at the Book-Cadillac Hotel in Detroit.

The gathering was held under the auspices of the Production Activity, which W. H. McCoy represents as vice-president of the Society, and its success was materially furthered by the active cooperation of the Detroit Section.

Attendance at the four sessions varied widely, but vigorous discussion followed the reading of almost every paper. The Production Dinner, sponsored jointly by the Detroit Section, marked the high spot in attendance with nearly 300 members and guests at the tables when Clyde R. Paton, Detroit Section chairman, acting as toastmaster, introduced R. H. Grant, vice-president, General Motors Corp., as the principal guest speaker.

"Even in large shops equipped in the most modern fashion, one frequently finds a condition of general ignorance as regards the proper purpose and use of cutting lubricants," W. D. Huffman of the Chevrolet Gear and Axle Plant told the manufacturing and oil men gathered at the opening session on Wednesday afternoon. "Too often experience and

Student Medal Presented

Norman L. Willett, a student at the University of Detroit, received the Detroit Section's gold medal awarded annually for the "best original thesis on an automotive subject contributed by an undergraduate student in any college within the territory of the Section." Mr. Willett had the assistance of John Pahl and William Sherman in his work, which concerned the design and construction of a utility glider.

Presentation of the medal was made by Dr. O. E. Kurt, the Detroit Section's vice-chairman for student activity, as a feature of the Production Dinner held Oct. 11, in which the Detroit Section cooperated. Mr. Willett presented an abstract of the thesis at the dinner.

Selection of the prize-winning thesis was made by a committee headed by Dr. Kurt and of which the other members were F. W. Wells, W. R. Griswold, R. N. Janeway, Maurice Olley, T. O. Richards and R. N. Upson.

shop tradition are the sole guides in selection of a given cutting fluid," he stated. (See page 17 for digest of Mr. Huffman's paper.)

Discussing Mr. Huffman's conclusions, C. B. Harding, Sun Oil Co., expressed the feeling that the field for cutting emulsions is much larger than has generally been recognized. Instead of being confined to simple cutting as in the past, he said, it is now being used in nut blanking, tapping, broaching and gear cutting. Emulsion does best, he stated, when the cutting tool is exposed and where the fluid can be applied directly to the tool in sufficient quantity and under some pressure. Under such conditions it lubricates, cools and washes away chips. He feels that in most cases the oil salesman is unable to contact with the responsible production man, largely because the importance of cutting coolants is not fully appreciated.

Emulsions should be controlled both as to mixture for the work to be done and in methods of distribution, Mr. Harding said. He suggested that the full amount of material first be put in half the total amount of water and agitated, and that the remaining water then be added with continued agitation. The mixture should be examined in the laboratory at least bi-weekly and greater cooperation should exist between the oil companies and the users, in Mr. Harding's opinion.

W. H. Oldacre, D. A. Stuart & Co., Ltd., commended the interest being shown in cutting fluids and urged greater cooperation and more exact observation of cutting conditions. One difficulty is the inability to correlate tests made by different parties. Temperature plays a greater part than many realize, he stated, and at temperatures above the boiling point, which are not uncommon with high speed tools, emulsions do not cool as well as straight oils. Water in emulsions also has a tendency to seep into bearings unless they are carefully guarded. Sulphurized oils have advantages of low cost and efficiency but the term is used so loosely that it fails to mean much in all cases.

Mr. Oldacre emphasized the need for specific information regarding the work to be done, the kind of material, feeds, speeds and kind of tool, when suggesting the best cutting fluid. Skin infections, in his opinion, are seldom caused by oils. When oil acne results however, astringent washes will usually cure it quickly.

One discusser pointed out that, since oil for cutting purposes is exempt from the lubricating oil tax, this function of cutting fluid action be referred to in some other manner to avoid confusion. The use of pastes that were dissolved in water was also brought out.

Erik Oberg, Machinery, stressed the need of specific information on cutting fluids for production men and likened the present confusion to the early days of carbon and high speed steels, when trade names rather than the contents and specific uses were given. Oil men pointed out the difficulty of doing this without greater cooperation of those responsible for production.

George F. Bowers, Standard Oil of Indiana, added to the discussion on sulphur content of cutting oils by referring to its effect in shortening the life of tools.

Balance of Rotating Parts

The problems involved in balancing of rotating parts were definitely clarified, especially for those who do not come into contact with balancing problems every day, by T. C. Van Degrift in the paper which, prepared in collaboration with J. M. Tyler, he read at the Wednesday evening session. The problem is not as mysterious as it might seem on first sight, these General Motors Research Laboratories' men contended. Then they went on to picture clearly the function of balance in the design of automotive engines. (See page 17 for digest of paper.)

In addition to his paper Mr. Van Degrift illustrated balancing machines for crankshafts and flywheels. He stated that the balance tolerances mentioned in the paper applied to a moderate sized passenger-car engine and when asked regarding a 500 hp. railcar engine intimated that only tests and experiment could determine the permissible tolerances. He further explained he and Mr. Tyler had been interested only in the balance at each end of the crankshaft as it required much less metal removal there than toward the center. Mr. Tyler explained, in answer to a question, that in balancing crankshafts for V-8 engines it is necessary to attach known weights to some of the crankpins to simulate the effect of reciprocating parts in the assembled engine.

Surface Broaching

E. S. Chapman, Chrysler Motors, Amplex Division, at the Thursday afternoon session, brought to the S.A.E. members actual production experience which his organization had been through recently with a considerable number of installations of surface broaching equipment, including the simple, single-stroke type of machine; the duplex type based on two broaches working alternately in the same machine; machines carrying two or more broaches, all of which act together on each stroke; and continuous rotary machines where no time is lost in handling the work.

"The shape of the piece, the number and location of surface to be machined and the required hourly production,"

Mr. Chapman pointed out, "all affect the selection of the most suitable type of equipment." (See page 18 for digest of Mr. Chapman's paper.)

In discussing Mr. Chapman's paper, R. S. Drummond stated that the examples it contained were typical except for the tolerances, which in most cases, were held as closely as in milling, usually within 0.001 in. plus or minus. The work speeds were frequently as high as 80 ft. per min. where the work was held rigidly. In fact, success in broaching depended largely on the fixtures used, he said. With the use of proper fixtures, including such features as dial indexing, many horizontal type broaching machines of older design are doing good work at very low costs. In some instances of this kind 500 pieces per hour were being obtained, Mr. Drummond stated. Surface broaching has already increased to the point of taking a large part of the broaches now made. Experience, both in making broaches and fixtures, has increased the life of the tools from 3 to 5 times. Except for blind holes, broaches can handle any work that can be milled. Depth of cut per tooth is sometimes as much as 0.012 to 0.016 in., though usually less, Mr. Drummond concluded.

Further discussion brought out data on broaching of cast iron. The only difficulties are hard spots and the abrasive, or lapping action of the metal. These same difficulties also apply to milling. With close grained iron of uniform quality, work is being broached to a limit of 0.0001 in. The finishing of heat treated material, such as keyways or splines in hardened gears, is now being done in regular production. Any hardness that can be touched with a file can be finish broached with the new types of tools taking cuts of 0.003 to 0.004 in. and with 300 pieces per grind. Broach cost is reduced by making the finishing portions so as to be easily replaced when they wear below size.

Purchasing Factory Equipment

Originally assigned to write a paper on "Study of Costs with Respect to Purchasing Production Equipment," J. E. Padgett, Spicer Manufacturing Corp., decided to view the subject from a more fundamental standpoint and discuss machinery and equipment policies in the light of the present business situation. He took the position that an engineering society can properly concern itself with such subjects because "in general, engineers are in that peculiar position where they are constantly translating theory into practice and they have to view both sides of the fence."

Voicing the opinion that general equipment purchasing policies will probably undergo a very radical change in the future if present legislative and financial conditions continue, Mr. Padgett stated that "experience in the last two years shows clearly that if a business is to carry on through difficult periods it must be free from excess fat in the way of unnecessary personnel or equipment.

"Difficulties are pretty well worked out now," he continued, "and we would be on the road to more normal operation, except that in the last few months, many acts and policies of the Federal government seem to have turned toward measures that will carry on and even intensify the unfavorable conditions. The result of tax measures, for instance, will be a freer distribution of cash in the way of dividends (if earned) and will result in less surplus than has been customary in the past. This will reduce the amount of capital available for putting into fixed assets, whether needed for replacement or for expansion.

Guest Speaker

R. H. Grant
Vice-President, General Motors Corp.

"It is probable," he stated, "that the best place for investment of limited working capital in many businesses is in consumption goods where it can be quickly liquidated as changes occur." (See page 18 for digest of Mr. Padgett's paper.)

Mr. Padgett's talk brought vigorous discussion and some argument from various sources.

R. E. W. Harrison of the Department of Commerce took issue with Mr. Padgett's paper as to taking into account the saving in overhead, pointing out that this had the precedent of being used by many successful concerns. He feels that it is always best to set up a re-equipment policy, but that each management must decide as to its application. Strictness as to excess plant and personnel should also apply to capital as that affects the price of the product as well. He cited instances where new machine equipment was the best paying investment that could be made. He also disagreed with Mr. Padgett as to the inability to secure loans and stated that progressive firms have secured funds for new equipment.

Herman H. Lind, general manager, National Machine

Tool Builders Association, pointed out that the policies toward new machinery were due to the codes made by business men themselves and that few of them restricted new equipment. He compared the progress of the building and automotive industries as examples of an industry which has recorded little progress and of one in which use of the best machinery has enabled the making of better products. He cited instances where dividends had been paid out of equipment reserves, which, he said, is equivalent to taking them from capital assets.

Equipment Reserves Essential

"Industrialists have always recognized that equipment loses value both through use and obsolescence," Mr. Lind pointed out. Then he went on to say: "The depreciation account is set up for two purposes: (1) to get the cost of the lessening value into the price of the product currently; and (2) to build a reserve for the replacement of tools as needed either because of wear-out or because a more efficient tool has come on the market.

"These reserves should not be merely another bookkeeping item. They should be set aside in cash or equivalent as a definite re-equipment sum. Too many companies are suffering today by reason of their machinery being obsolete and of having no money to buy new. Some have paid dividends out of their reserves when, as a matter of fact, such payments represent an actual distribution of capital.

"If the initiative and rugged individualism which is responsible for the material progress of our country is as genuine as we think it is, it will not let progress stop, but will go forward to building more and better products for the enjoyment of an ever increasing range of people. The use of modern machinery is a means to that end.

Progress Lies Ahead

"If our leaders of industry and leaders of the nation are worthy of the name, they must not and cannot call their work completed until the last family in the land willing to contribute his part in the effort shall have and enjoy all those things that science and ingenuity have brought forth up to this time, and things that are on their way. Restrictions on whole industries through codes or laws or by agreement may hinder the progress of this development. Mistaken policies of individual units may retard it, but for one, I feel that our industrialists are too well grounded in the proven principle of progress not to overcome such artificial obstacles, and that after a relatively short respite we shall be going forward once more with all the progressiveness, initiative and confidence that we ever had, and more."

Prior to the introduction of R. H. Grant at the Production Dinner on Thursday evening, John A. C. Warner, secretary and general manager of the Society, spoke briefly of the importance of human problems in industry today.

"Today's human problems in industry," he said, "are identical fundamentally with those of the pioneers. But there is this difference—that our modern manufacturing executive has to operate a comparatively long, complicated system of communication through which the practical elements of mutual understanding and sympathetic employer-employee relationships must be transmitted and maintained. . . . With this increasing complexity has come a need, greater than ever, for finer and more intelligent 'connections'; for a smoother interchange of knowledge and understanding. This oft-repeated idea meets with ready agreement, but does not result in enough specifically directed action. This accounts for one of our greatest current responsibilities."

Drawing on his many years of experience in the merchandising phase of the automobile industry, R. H. Grant took as his theme some of the sales factors of most current importance. Among other things, he said:

"In selling work, one has to look at things from their favorable angles. Selling is a little different than laying down a production schedule; different than computing a company's finances; different than the working out of engineering formulas. In selling it is much better to be optimistic, unless things point definitely to reasons why you should not be.

"In automotive engineering, the economic situation must be given consideration. In these days of keener competition, it is necessary to get into design and production the feeling of the economic situation immediately ahead.

"Had we always been working in that direction to the highest degree, our present-day vehicles probably would be even better than they are. There is no doubt in my mind that ahead of us somewhere lies another period of expansion, during which a certain degree of extravagance will prevail. And those people who are able in advance to sense that debtor market and take advantage of it are going to outdo their competitors who may not have the sales and the engineering sense to cash in on a good opportunity when it comes along.

"We need even better understanding and even better team play in the future than in the past between the sales and engineering divisions, in order that the engineering side of the picture may gain everything from the sales end that the latter is capable of furnishing. In the sales department, we are in contact with our dealers and salesmen, and, to a certain degree, with the public, and we certainly have the responsibility for keeping our hands on the public pulse. On these efforts of the sales department, the engineering division ought to cash in to the fullest possible extent.

"I don't believe that any engineering department is going to take for granted all it hears, and I think in addition to the sales group contact, it is quite important that the engineers get their own 'feel' of the situation so that they may intelligently check ideas which are passed on from the sales division."

Acceleration: *1935 Model*

THE "Thirtieth Anniversary Dinner" of the Society, during Automobile Show Week in New York, will inaugurate a year of heightened interest in the Society and the profession of automotive engineering.

Start the year right—save the date for the dinner and plan to be at the Annual Meeting in Detroit. Everyone you want to see and every car you want to see will be in New York for Show Week.

For the first time since 1910, for instance, every automobile manufacturer will be in the show. Keep a fountain pen handy to sign an early reservation for the "Thirtieth Anniversary Dinner," the high spot of Show Week for automotive engineers.

Remember!

"Thirtieth Anniversary Dinner," New York, Jan. 7
Annual Meeting, Detroit, Jan. 14-18

Beginning a big year for the S.A.E.

Production Meeting Papers in Digest

HERE are digests of all the papers presented at the National Production Meeting, held in Detroit, Oct. 10 and 11, 1934.

* * * *

Some of these papers will be printed in full in the S.A.E. JOURNAL.

Mimeographed copies of *all of them* will be available, until current supplies are exhausted, at a cost of 25 cents per copy to members; and at 50 cents per copy to non-members. Orders for mimeographed copies must be accompanied by remittance and should be addressed to Sessions Secretary, Society of Automotive Engineers, 29 West 39th St., New York.

Cutting-Oil Session

Wednesday, October 10

Cutting Oils and the Fundamental Characteristics in Their Selection—*W. D. Huffman, Chevrolet Motor Co.*

IN this paper the types and purposes of cutting oils most generally used are discussed. There are two types, the non-emulsifiable and the emulsifiable or soluble oils. The fundamental characteristics which more or less should govern their selection are listed as follows:

1. Soluble cutting oils—
   - (a) Ability to emulsify
   - (b) Tendency to remain stable without separation
   - (c) Tendency to prevent corrosion and give satisfactory finish
2. Non-emulsifiable cutting oils—
   - (a) Quantity and nature of saponifiable material
   - (b) Quantity of combined sulphur not in natural combination

An appeal is made for the tabulation of the properties and application of these oils, in order that, in the distribution of these data, a certain degree of standardization may be accomplished and thus remove the confusion that apparently now exists.

The problem of infection among those coming in contact with the oils is discussed, and the conclusion drawn that much of it might be averted by a more careful attention to personal hygiene and sanitary working conditions.

It is stated that in the application of these oils to various operations, a naturally fundamental and obvious aim should be the securing of an oil which will serve the same purpose on different machines and different jobs. The nearest approach to an all purpose cutting lubricant might be found in an attempt at more general use of emulsions.

The problem of broaching and grinding is taken up and it is suggested that in the former, soluble oils might find greater application than they do, and that the finish in the latter might be improved by provision being made for removal of small particles and abrasives.

Dynamic Balancing Session

Wednesday, October 10

Balancing Problems in Automotive Engineering—*T. C. Van Degrift and J. M. Tyler, General Motors Research Laboratories.*

THIS paper pictures the function of balance in the design of automotive engines.

The balance of a thin rotating part is obtained by distrib-

uting its mass so that its center of gravity is at the axis of rotation. The balance of a long rotating part (such as a crankshaft) is obtained by distributing its mass so that its gravity axis is on the axis of rotation. The thin part is balanced statically, the long part is balanced dynamically.

The unbalance of reciprocating parts in an engine must be balanced by other reciprocating parts. The balance of reciprocating parts is a matter of the design of the engine. It is known as the inherent balance of the engine. Practically all American passenger car engines are inherently balanced.

Balancing machines available for the balancing of rotating parts cover a wide variety of design, each machine being suited to its individual purpose. For precision balancing in production, however, certain definite requirements must be fulfilled, most important of which are accuracy of balance and speed of handling.

The balance of an assembled engine depends on the balance of the individual parts and on the concentricity of pilots and the fits of guides. The matching of reciprocating weights and the location of crank pins is also important. If all of the unbalances of individual parts add up in the same direction a large unbalance will be present in the assembled engine.

Broaching Practice Session

Thursday, October 11

Machinery and Equipment Policies in View of the Present Business Situation—*J. E. Padgett, Spicer Mfg. Corp.*

GENERAL equipment policies will probably undergo a radical change in the future if the present legislative and financial conditions continue, the author states, pointing out that there has been a decided shrinkage of working capital in most manufacturing institutions during the last several years.

Limitations in working capital will probably mean that what is available will be concentrated on distribution. Positing such a condition, the author analyzes its effect on the purchase of new equipment, depreciation of plants and structures, and other factors of interest to the production engineer.

The greatest hope for the future, he says, is that we are probably past the bottom of the present economic wave. When long-term planning is considered, he believes, a time such as the present is the time when equipment should be purchased in the largest amounts, because such purchases will prepare the business for correct low-cost, successful manufacture during ensuing expansion, and will also take advantage of all the developments and inventiveness forced out during hard times.

Production Experience with Surface Broaching—*E. S. Chapman, Chrysler Motors, Amplex Division.*

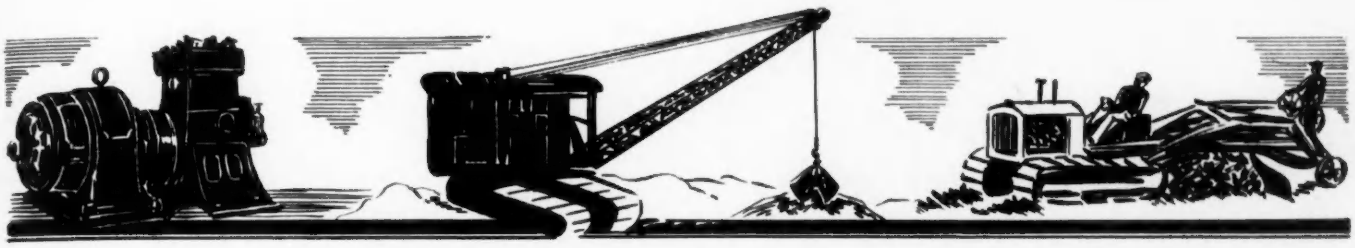
THIS paper gives actual performance history on a variety of types of work and several types of broaching equipment.

The data in each case are based on a production of several hundred thousand parts and should therefore have some value to anyone considering a change of method or provision of equipment for new production involving similar operations.

Following is a tabulated summary of the more interesting figures involved. In two cases direct comparisons are available with milling machine performance. In one case the milling cutter cost is about nine times the broach cost per piece and in the other, about three and one-half times the broach cost per piece.

Summary of Surface-Broaching Production-Data

Part Name	Material	Type of Machine	Broach Speed, Ft. per Min.	Number of Parts per Grind	Broach Cost Per Piece (Dollars)
Yoke	Forging	Continuous Rotary—Mechanically Operated	8	5,000	0.0036
Control Arm (2 Operations)	Forging	Single Acting Double Ram Hydraulic and Single Acting Mechanical	44	5,000	0.0023 0.0025
Knuckle	Forging	Single Acting Double Ram Hydraulic and Alternating Double Ram Hydraulic	33	7,000	0.0022
Steering Shaft	Forging	Alternating Double Ram Mechanical	27	10,000	0.0013
Free Wheeling Cam	Forging	Alternating Double Ram Mechanical	38	8,000	0.0006
Steering Housing	Malleable Iron	Single Acting Single Ram Hydraulic	18	2,500	0.0018
Control Arm Pin	Bar Stock	Single Acting Double Ram Mechanical	30	9,000	0.0019



Set Plans for December Tractor Meeting

THE second general Tractor and Industrial Power Equipment Meeting held by the Society since the revival of the tractor industry's interest in S.A.E. activities is scheduled for Chicago on Dec. 5 and 6. The meeting has been arranged in cooperation with the American Society of Agricultural Engineers, in conjunction with their annual meeting in Chicago at the time of the National Live Stock Exhibition. The S.A.E. sessions will be preceded by two days of sessions of the Power and Machinery Division of the A.S.A.E. The S.A.E. sessions have been devoted to the general subject of wear factors in engines, which was decided by the S.A.E. Tractor and Industrial Power Equipment Committee at its meeting last April to be the most important topic for this winter meeting. The subjects of morning and afternoon sessions of both days will be important factors of engine wear, treated by men who are particularly qualified to handle the subjects in their respective fields.

The Chicago Section had originally scheduled its regular December meeting for Dec. 4 but has cooperated fully and heartily in changing the original plan to meet the tractor meeting arrangements. The sessions on Wednesday evening, Dec. 5, will accordingly be under the auspices of the Chicago Section.

The preliminary program for the Power and Machinery Division meeting of the A.S.A.E. lists six sessions on Dec. 3 and 4. The first session will be devoted to tractor and implement wheels. Rubber tire applications to tractors and other farm equipment will have an entire session devoted to them. A third session will be devoted to the study of power requirements for various types of agricultural machinery.

The general outline of the A.S.A.E. sessions is given for the benefit of members who will be interested in this part of the general meetings and in attending some of the A.S.A.E. sessions.

The A.S.A.E. is interested in agricultural engineering and general agricultural machinery while the S.A.E. is interested in the automotive power agricultural and industrial machinery. Thus the activities of the two Societies meet but do not overlap. It is believed that the cooperative meetings as arranged will dovetail well and provide a full week's program of interesting values to both the S.A.E. and the A.S.A.E. members.

S.A.E. Tractor and Industrial Power Equipment Meeting, Dec. 5-6

Stevens Hotel, Chicago

WEDNESDAY, DECEMBER 5

Cylinder and Piston Session—Morning

***Chairman*, L. B. Sperry, International Harvester Co.**

Cylinder Finishing—K. W. Connors, Micromatic Hone Co.

Piston and Piston Ring Design—(Speaker to be announced later)

Air Cleaner Session—Afternoon

***Chairman*, J. H. Holloway, Northwest Engineering Co.**

Paper—Fred R. Nohavec, Donaldson Co., Inc.

Paper—R. N. Burckhalter, Michiana Products Corp.

Informal Open Discussion

Diesel Session—Evening

***Chairman*, R. E. Wilkin, Standard Oil Co. of Indiana**

Paper—O. D. Treiber, Hercules Motor Corp.

THURSDAY, DECEMBER 6

Valve Session—Morning

***Chairman*, C. E. Frudden, Allis Chalmers Mfg. Co.**

Design and Materials of Valves and Valve Gears for Maximum Service—Robert Jardine, Wilcox Rich Corp.

Discussion (prepared and informal, names to be announced later)

Engine Lubrication Session—Afternoon

***Chairman*, Elmer McCormick, John Deere Tractor Co.**

Cold Starting Problems in Relation to Engine Wear—A. J. Blackwood, Standard Oil Development Co.

Discussion (prepared and informal, discussers to be announced later)

News of the Sections

- Crane on Future Cars
- Leaf Springs at Pittsburgh
- Maori's Dance for Canadian
- Extreme-Pressure at Baltimore

Carburetor's Story Shown by Figures

• Chicago

The story of carburetor development, traced from the simplest type up to the present design, was presented to members and guests of the Chicago Section at their first Fall meeting, which was held Oct. 2 at the Hamilton Club.

The meeting, which was designated South Bend Night, was especially well attended, there being 138 at the technical session, and 99 being present at the dinner at which an honorary life membership was presented to Colonel O. B. Zimmerman for distinguished service rendered to the Society. Chairman Wilkin introduced D. G. Roos, president of the Society, who made the presentation address

In explaining the various principles which are incorporated in modern carburetor designs, Albert H. Winkler, Jr., Bendix Products Co., the technical speaker, made use of a pictorial representation in cross section of the carburetor. The background represented the most simple principle, and, as need for refinement was explained, additional parts, colored in red and yellow, were attached to the board, so that the model continued to grow as the talk progressed, until it represented a carburetor of modern design.

Various units added showed the addition of the float mechanism, main fuel jet, air bleed, throttle, idling system, venturi, economizer jet, accelerating pump and choke.

The discussion also took up a number of service problems and showed steps taken from an experimental and laboratory standpoint, in order to determine proper jet sizes for various motors.

During the discussion which followed, it was brought out that jets smaller than those originally specified could sometimes be used, but there was danger of getting a mixture so lean that valves of spark plugs would be burned. Reference to the automatic choke was also made, and Mr. Roos pointed out that this was a life saver as far as the down-draft carburetor was concerned, for, with manual manipulation of the choke, there was greater danger of engine flooding than with an up-draft carburetor because of the fact that the gasoline was flowing by gravity to the motor.

In general, Mr. Winkler stressed the fact that the modern gasoline engine is a combination of units, all of which taken together comprise the finished power plant; and that the fundamental principle of servicing is a proper coordination of the functions of all the various units to secure the satisfactory and economical operation of the whole.

O. B. Zimmerman

Life Membership in the Society was presented to Col. Zimmerman at a ceremony which was part of the Oct. 2 meeting of the Chicago Section. The presentation was made by President D. G. Roos who paid high tribute to Col. Zimmerman's long participation in the affairs of the Society.

Among the guests who attended the meeting was John A. C. Warner, manager of the Society, who spoke regarding the Society's activities during the past year. He covered particularly the Sections, Meetings, Employment, Standards and Membership activities, and reported on finances.

Cause and Effect Of Vibration Shown

• Northwest

The causes of vibrations, and their elimination, was the subject of the October meeting of the Northwest Section. Prof. A. M. Winslow, University of Washington devoted his paper to causes with some specific examples, while H. L. Hanawalt, Engineering Specialty Co., Seattle, talked on "Modern Methods of Eliminating Vibrations." The subject was of sufficient interest and novelty to bring questions from many of the 50 members and guests present.

The general features of vibration phenomena are easy to explain according to Professor Winslow, but the technical details soon lead into deep water. He classified vibration into two distinct types: common or bouncing and torsional or transverse vibration. He explained the use of the vibrometer for measuring horizontal and vertical motion as in spring action and set out in some detail the function of shock-absorbers, springs and other instruments designed to dampen or halt vibration. The cause of crankshaft failure is often torsional vibration, he explained, and pointed out that it is difficult to avoid all bad amplitudes in the automobile engine due to variation in speed.

Examples of the ill-effects of unbalance and how to fight them gave a practical turn to Mr. Hanawalt's address. He explained the results of tests showing that a 4½ in-oz. unbalance in the front-wheel assembly of a car can climb to 41 lb. at a speed of 70 miles and cause severe shimmy. Seven bad effects of unbalance were enumerated: (1) discomfort of vibrations; (2) mechanical troubles, such as worn bearings, etc.; (3) power losses, from 25 to 50 per cent due to unbalance; (4) increased fuel consumption; (5) increased lubricating oil consumption; (6) loosening of parts on engine, such as bearings; and (7) damage to mountings or surroundings of powerplant.

Geniesse Gives Oil Economy Precepts

• Philadelphia

A summary of existing knowledge concerning the factors entering into fuel and oil utilization was presented by Dr. J. C. Geniesse, research engineer, Atlantic Refining Co., at the Oct. 10 meeting of the Philadelphia Section in his paper which was titled, "Fuel and Oil Economy for the Operator." Dr. Geniesse touched briefly on the enervating effect of gasoline taxes which amount to as much as 25 to 35 per cent of the fuel bill. Then in order, he showed the effect of air fuel ratio and its limiting values and the role of gas analyzers and other devices for checking thermo efficiency.

One effect frequently overlooked by operators, he said, is that of variations in atmospheric temperature which may cause a difference of 20 per cent in fuel consumption. Finally the author showed the advantages of the 10-W and 20-W oils from the standpoints of better starting, quicker circulation, improved engine life and improved gasoline mileage. Among those who participated in discussion of Dr. Geniesse's paper were B. B. Bachman, William G. Mayer, C. O. Guernsey, Harry F. Huf and Joseph Geschelin.

Registered attendance of the meeting was 125 with 53 present for the dinner which preceded it. Thomas C. Fraser, auto superintendent, Standard Oil Co. of Pennsylvania, presided at the meeting and led the discussion.

Method Suggested For Bettering Repairs

● Oregon

Three speakers were on the program at the Sept. 14 meeting of the Oregon Section, held at the Congress Hotel in Portland. W. H. Paul, instructor, Oregon State College, described

J. C. Othus S. H. Graf

Cooperating with the Oregon Section in automotive courses and extension work at Oregon State College

the proposed automotive courses at the college, a project in which the Section has taken considerable interest and to which its members have contributed a substantial amount of equipment. H. C. Carter, chief engineer, The Iron Fireman Mfg. Co., gave a talk on the "Possible Application of Production Line Methods to Automotive Maintenance Work." L. L. Adcox verbally donated space in his automotive school for holding an extension course in automotive engineering to be conducted by the faculty of the Oregon State College. Professor Graf of the College, in prefacing the talk by Mr. Paul, formally accepted material donated to the course by members of the Section.

In his talk Mr. Carter pointed out that his organization had been able to take the production methods of the automobile factories and apply them to comparatively small output with a consequent reduction in costs. By analogy, he believes there is something wrong when the automobile factory can make a complete car at no more direct labor cost than is required by the average automotive repair shop to overhaul the same car.

The future of the automobile industry, he said, depends upon the utilization of methods such as those employed by the automobile factory organizations. The repair shop must set itself up on a production basis. A series of standard operations can be developed and these would be performed upon all cars brought in for servicing regardless of their specific trouble. Such a plan could be broad enough to include repairing of most of the troubles of the average car. These standardized operations, Mr. Carter believes, could be performed with less overall time expenditure and at less cost than the present system of talking to the customer and diagnosing and repairing the trouble which has caused the immediate breakdown.

The sales department could be taught to merchandise this type of service at standard prices. A repair organization working on these general principles, Mr. Carter stated, would be a creative business organization and no longer be considered by vehicle manufacturers as a "poor relation" willing to take left-over and undesirable business.

Attendance at the September meeting, first of the season for the Oregon Section, was 49 at the dinner, which preceded the meeting, and 54 at the meeting itself. Discussion of the talks was rather limited. Fred Dundee, manager, Dundee Auto Repair and Machine Works, Portland, in replying to Mr. Carter's remarks, took the position that shop work is custom work and not for quantity output.

October Section Attendance

Attendance at October meetings of the Sections indicates in many cases a healthy gain over attendance at corresponding meetings last year. Where no gain was made the figures compare favorably with those of last year.

Sections which showed a big increase at this year's October meeting were:

	1933	*1934*
Baltimore	23	172
Chicago	53	138
Indiana	225	300

Maori War Dance Ends a Meeting

● Canadian

The Canadian Section opened its season with a meeting on Sept. 19 at which 70 members and guests were present. The speaker was John W. Collins, trade commissioner from New Zealand to Canada and the United States. Mr. Collins described trade relations between New Zealand and Canada with particular regard to the automobile industry. Following the business part of the address, he showed slides of scenery and sports in New Zealand. During this part of the program those present were surprised when a Maori warrior stepped into the room and gave an exhibition Maori ha-ka, or war dance.

Uses of Rubber Shown by Schippel

● Cleveland

"Uses of Rubber for Transportation" was the title of a paper by H. F. Schippel, B. F. Goodrich Co., Akron, delivered at the Sept. 17 meeting of the Cleveland Section. The meeting was sponsored by K. D. Smith, superintendent, Tire Division, B. F. Goodrich Co., who acted as chairman. General discussion of the paper centered principally on the effect of heat on tire wear and on the cutless rubber bearing. The meeting was held at the Cleveland Club and was attended by about 55 members and guests. A dinner preceded the meeting and was attended by 31.

Dr. Edgar Tells Of Antiknock Work

● Washington

Dr. Graham Edgar, vice-president and director of research of the Ethyl Gasoline Corp., discussed engine performance in relation to antiknock qualities of gasoline before a group of about 50 members and guests of the Washington Section at a meeting held Oct. 1, following a dinner at the University Club.

Dr. Edgar showed by means of slides how the knock in an engine appears when all of the unburned charge in the cylinder ignites spontaneously. Although engine displacement has remained practically constant for the past few years, power output has increased about 90 per cent, a large part of which has been due to the use of higher compression ratios. A group of slides showed graphs of engine performance when compression ratios and other factors were varied.

Considerable discussion followed the meeting in which Dr. H. C. Dickinson, past president of the Society and several government officials and operators took part. In reply to a question by Dr. Dickinson as to what an operator should do about buying fuel for equipment which he already has and must use, Dr. Edgar said that if the gas he is using does not knock it is good enough. In other words the antiknock quality of a gasoline in itself has no particular value unless it is needed to prevent knock.

Compression ratios as high as 15 to 1 have been used though these high ratios are not practical as the cost of the fuel far exceeds the gain derived from the use of this high ratio. The maximum compression ratio which should be used must be arrived at by a consideration of the characteristics desired and the permissible cost of obtaining them.

Marshall Reports On S.A.E. Research

● No. California

A. G. Marshall, assistant superintendent, in charge of research and development, Shell Oil Co., presented an informal report on S.A.E. research in the petroleum field at the Sept. 11 meeting of the Northern California Section. Principally the paper was a review of things seen and heard at the Semi-annual Meeting of the Society at Saranac Inn, last June.

Members and guests to the number of 72 attended the meeting which was preceded by a dinner attended by 54.

G. H. Mosel

Elected Chairman of the Northern California Section for the 1935 season

Describes Army's Motor Equipment

● Indiana

Automotive developments of the U. S. Army were described by Maj. L. H. Campbell, Jr., Ordnance Department, Rock Island Arsenal, at the Oct. 11 meeting of the Indiana Section, held at the Athenaeum in Indianapolis. The meeting drew an attendance in excess of 300 and was the largest opening session reported in recent years by the Indiana Section.

After introducing the subject, Major Campbell gave a condensed history of the development of Army automotive equipment from the time of the world war including tanks, tractors and scout cars. The talk was illustrated with slides and five reels of motion pictures of tests of automotive equipment were shown. There was no discussion.

At the dinner which preceded the meeting 75 attended to greet a number of distinguished guests which included Maj. Robert Tyndall of the National Guard, Maj. R. H. Habbe, president of the Reserve Officers Association, delegations of officers from Fort Benjamin Harrison, Corps Area officials and other National Guard and Reserve Officers.

Crane Foresees Gradual Changes in Car Design

HENRY M. CRANE, technical assistant to the president, General Motors Corp., predicted only gradual changes in car design in the near future in his address before a capacity audience of members and guests of the Metropolitan Section on Oct. 8.

Mr. Crane, a past president of the Society, spoke as a member rather than as an official representative of General Motors, making it clear that the opinions he expressed were not necessarily those of the corporation with which he is affiliated. Reviewing recent trends in passenger car design, Mr. Crane said that there have been, in recent years, noteworthy increase in engine power, resulting in part from higher engine speeds, higher compression and better fuel, but pointed out that this has been accompanied by a marked increase in the weight of engines and of cars, although the power weight ratio is high. He does not anticipate any radical changes in engine design, such as the adoption of a new cycle in the near future, and indicated that there is now no need for more than eight cylinders, at least in large production models.

Transmissions, he believes, are now quite satisfactory and no early change to radically new types is indicated. Power shifting would be quite easily accomplished with current synchromesh types but so little gear shifting is required that the extra complication is of doubtful value. Overdrive yields some advantages in the case of cars driven much at high speed in open country, but sometimes interferes with maneuverability, particularly when passing other cars, the speaker said. Some changes in springing at the rear may be undertaken, but the current arrangement of leaf springs in the rear is quite satisfactory for most road and driving conditions, in Mr. Crane's view. Front suspensions, of the independent type, he indicated, have proved their worth, especially in fast driving on poor roads, but have increased cost of production. He anticipates little change in current types in the near future.

Streamlining, as a name and as affecting appearance, Mr. Crane indicated, had gained public acceptance and is likely to be continued, but its effectiveness in present forms, as regards power and fuel saving has been over-rated. Really effective streamlining involves marked rearrangement of body and chassis, he said, and appeared to question whether such changes would be worth while, especially as they may involve a narrow rear seat which would not be acceptable to most purchasers of cars made in large quantities.

Improvements in brakes have not kept pace with speed increase and much must be done to effect needed changes, though radical departures seem unlikely, in Mr. Crane's view. Wider use of cast-iron drums is anticipated and much needs to be done and is being done to assure uniformity of brake action under varying weather conditions. The use of brakes making use of power application may be expected to increase, Mr. Crane believes.

Discussion invited by Chairman Joseph A. Anglada was offered by only a few speakers, those taking part including Austin M. Wolf, M. C. Horine, Herbert Chase and Lowell H. Brown. Some of these speakers took issue with Mr. Crane's remarks concerning streamlining, pointing out that it does not of necessity increase car length and that tests of really well streamlined cars have shown them decidedly effective in power and fuel saving, even at speed of only 40 m.p.h. Some streamlining on front, top and rear of production models has been good, but fenders and runningboards still create eddying at the sides of these vehicles, it was pointed out.

Sid. G. Harris, chairman of the Section, announced the appointment of T. C. Smith as vice-chairman in charge of the Transportation and Maintenance Activity of the Section.

Larsen Presents Latest E. P. Notes

● Baltimore

Members of the Baltimore Section were brought up-to-date on the subject of extreme-pressure lubricants by C. M. Larson, supervising engineer, Sinclair Refining Co., New York, who presented a paper on "The Realm of Extreme-Pressure Lubricants" at the Oct. 4 meeting. Mr. Larson described the conditions which led to the establishment of the extreme-pressure classification for lubricants which are designed to carry pressure much greater than those which can be carried by viscosity alone. Reference was made to several types of assembly requiring extreme-pressure lubricants and to research sponsored by the Society for the purpose of arriving at suitable classifications of lubricants within the field.

Mr. Larson's paper was heard by 172 members and guests of the Section with the preceding dinner attendance placed at 66. Discussion of the paper was contributed by Dr. W. B. D. Penniman, consulting chemist, Arthur B. Gardner, president, United Oil Co., Inc., H. Clausen, manager, lubricating oil department, American Oil Co., and John A. White, consulting transportation engineer. The meeting was the largest in the history of the Baltimore Section, according to available records.

Distinguished Gathering Greets T. O. M. Sopwith at Luncheon

● Metropolitan

On Sept. 28, the Metropolitan Section arranged a luncheon at the Commodore Hotel, New York, in honor of T. O. M. Sopwith, British challenger for the America's Cup, and a celebrated aircraft designer. In the picture, Mr. Sopwith is seated at the center of the head table, flanked by D. G. Roos, president of the S.A.E. and William B. Stout, presidential nominee for 1935. Most of the S.A.E. Council is seated at the table in the foreground. Besides tributes from Messrs. Roos and Stout, Mr. Sopwith was greeted by distinguished guests of the Society, including Gar Wood, George Townsend, president of the American Power Boat Association; Lester Gardner, secretary, Institute of the Aeronautical Sciences. Sid. G. Harris, chairman of the Metropolitan Section, welcomed the guests, who numbered about 75.

Regional Transportation and Maintenance Meeting

Newark, N. J., Nov. 8, 9 and 10 — **Hotel Douglas**

Since the first announcement of the Regional Transportation and Maintenance Meeting (pages 20 and 50 of the October issue of the Journal) plans for the exhibition of vehicles and equipment at the meeting have been considerably expanded. Many other features of the program have been enlarged or modified to provide a program of superlative interest to transportation and maintenance men in both the vehicle and aircraft fields. The meeting, which is being sponsored jointly by the Metropolitan Section, Society of Automotive Engineers, the New Jersey Motor Truck Association and the Newark Chamber of Commerce, will be held at the Hotel Douglas, Newark, N. J., on Nov. 8, 9, and 10. The exhibition of equipment will be open all three days at the Essex Troop Armory, New Jersey National Guard, 120 Roseville Avenue, Newark, N. J.

Among the speakers who have been added to the program since the first announcement are, William B. Stout, nominee for president of the Society for 1935, who expects to have on exhibition a new type of bus he has developed. Clarence Chamberlin, past vice-chairman for aeronautics of the Metropolitan Section, will act as chairman at an evening session on the business utilization of air transport facilities.

Diesel, butane, and propane-burning units, streamlined vehicles, trucks and special equipment will be among the exhibits at the Essex Armory.

All members of the Society in section territories east of the Mississippi River are receiving special invitations to the Regional Meeting and all other members of the Society and interested persons are invited to attend.

EXHIBITION OF MODERN VEHICLES AND EQUIPMENT

Essex Troop Armory, Newark, N. J.

Nov. 8, 9 and 10

Leaf-Spring Men Tell of New Car

• Pittsburgh

The speaker at the Oct. 2 meeting of the Pittsburgh Section was sponsored by John H. Shoemaker, commissioner of the Leaf Spring Institute, who spoke on the conditions leading up to the Leaf Spring Institute's development of a motor-vehicle using leaf springs for independent wheel suspension at four points.

Karl K. Probst, consulting engineer for the Institute, described in technical detail how the job was accomplished. The meeting drew an attendance of 175 with 66 members and guests attending the dinner which preceded. Discussion of the two speakers' remarks was offered by Joseph Harvey, Murray Fahnestock, Arthur Platt, Ralph Bagley and George W. Brisbin.

The first S.A.E. appearance of the newest development in independent springing and frame design, the contribution of the Leaf Spring Institute, was at the Pittsburgh Section meeting.

The report of the meeting, furnished by the Pittsburgh Section, follows:

"On a raised platform, every detail of the chassis exposed and floodlighted, stood the answer of the Leaf Spring Industry to the challenge of independent springing—an American car of revolutionary design, with four knees, two wishbones, a backbone, and leaf springs throughout.

"Mr. Shoemaker, introduced by R. N. Austen, traced the development of springing to the present time, and told of events leading to the formation of the committee to investigate well-known types of independent springing. This investigation, plus the whole-hearted cooperation of the members of the Institute, has resulted in a unique chassis design, incorporating leaf springs and individual suspension of all four wheels. The advantages of this design, its practicability, serviceability, and general engineering soundness have been proven by the most severe road and laboratory tests, according to Mr. Shoemaker.

"Mr. Shoemaker's remarks, and the paper presented by Mr. Karl Probst, stressed the fact that two fundamental results were sought during this development—*reduction of weight and simplification of chassis*. That these two considerations were paramount through the investigation of forty or more independent leaf spring systems is evidenced by the actual construction and performance of the car itself. Mr. Probst's paper covered in detail the reasons for incorporating the various units into the design and described them in detail, with slides to illustrate. A brief description of the car follows.

"An unequal parallelogram type of suspension, with two parallel transverse springs as the lower arm, combined with a shock-absorber link as the upper arm, permits a compromise between camber change and track variation in the interest of most satisfactory tire wear. This design, based on a large cumulative experience, also permits moving the powerplant forward—an essential consideration in streamlining, and conducive to better weight distribution. In the design adopted, the second leaf wraps around the eye of the main leaf, and a progresive spring seat control is incorporated on the deflection side. This design has eliminated the need for rubber frame bumpers and has made it possible to use little or no shock-absorber control on the compression stroke, according to Mr. Probst.

"Eccentric threaded pins and screw bushings throughout not only make for economy of construction but permit the specification of plus or minus 1/16 in. in spring length for satisfactory assembly. Caster and camber ad-

(Continued on page 24)

Student Branches Elect Officers; Activity Begins Broad Program

• Student Activity

THE Student Activity of the Society has got under way rapidly with the opening of the new season. Almost all the student branches have elected their officers for 1934-1935 and are proceeding with the establishment of constructive programs. Several sections are broadening their cooperation with students in nearby institutions where their student branches are maintained.

In the news report of the last Oregon Section meeting will be found an account of some of the work being done by that Section. At the general Production Meeting of the Society in Detroit, O. E. Kurt, vice-chairman of the section for student activities presented a medal to the student in the Detroit area who had offered the best original thesis on an automotive subject during the past year. Special automotive courses with S.A.E. cooperation are being offered by the Massachusetts Department of Education and the public school system of Los Angeles, Calif. These are a few of the high spots. Other activity is under way but has not yet been reported in detail.

Contact of the general Society headquarters in New York with all phases of student work in the Society is now under the supervision of E. F. Lowe, assistant general manager. Supervision of the Society's policy and efforts in this connection is placed with Special Student Activities Committee of which Harold Nutt is chairman and F. K. Glynn, William B. Stout and Harry T. Woolson are members. For the information of all members of the Society who may be interested in affiliating themselves on phases of the student work, an up-to-date directory of student branch officers and cooperating sections follows:

STUDENT BRANCHES

Officers 1934-35

Massachusetts Institute of Technology

Chairman—Warren B. Schott
Vice-Chairman (Automotive) — Richard Purcell
Vice-Chairman (Aeronautic) — John Bradner
Vice-Chairman (Marine)—John Myers
Secretary—Richard Bryant
Treasurer—Winthrop Scott
Chairman Membership Committee—Arthur Greenblatt

New York University

Chairman—C. L. Hall
Vice-Chairman (Aeronautic)—R. W. Logan
Secretary-Treasurer—R. W. Thompson

Ohio State University

Chairman—Fletcher G. Bennett
Vice-Chairman—Brandon G. Rightmire
Secretary-Treasurer—Kenneth R. Mercy

General Motors Institute of Technology

Chairman—W. F. Whitenack
Vice-Chairman—H. W. Broslavik
Secretary-Treasurer—W. E. Schmidt

University of Detroit

Chairman—A. J. Assessor
Vice-Chairman—Frank Bowers
Treasurer—Cletus Jenny
Secretary—Sidney M. Gamsu

Sections Having Student Activities

Detroit Section—O. E. Kurt, Vice-Chairman of Student Activities—cooperating with students at University of Detroit and General Motors Institute of Technology. (Student medal to be awarded at Production Meeting)

Metropolitan Section — Warren Tiegler, Chairman Student Activity Committee—cooperating with New York University.

New England Section — Cooperating with Massachusetts Institute of Technology.

Oregon Section — Cooperating with Oregon State College (no student branch here).

Philadelphia Section — Cooperating with Swarthmore, Lehigh, Drexel and Temple Universities (no student branches).

Pittsburgh Section — D. Roberts Harper, Chairman Student Activity Committee—cooperating with Allegheny Vocational School, University of Pittsburgh, and Carnegie Institute of Technology.

Northern California Section — Student Activities Committee—Prof. U. A. Patchett (Stanford), Prof. L. Boelter (U. of Calif.). Cooperating with the students at Stanford University and University of California.

Dayton Section—Contemplates holding one meeting during this administrative year at the Ohio State University, Columbus, in conjunction with the members of the S.A.E. Student Branch at that University.

Leaf-Spring Men Tell of New Car

• Pittsburgh

(Continued from page 23)

justment is obtained by means of an eccentric pin and slotted bushing in a pivoted yoke at the end of the shock-absorber link.

"The rear transverse springs are mounted on the bottom of the differential unit, which is mounted on rubber cushions in the frame itself. Power is transferred to the full floating wheels by means of two short drive shafts with two universal joints each. Except that the springs are farther apart in the rear, the balance of the design is similar to the front. The eccentric screw-thread pins are also used here to secure perfect rear-wheel alignment.

"To prevent excessive sway on curves, a torsional stabilizer is incorporated in the rear design.

"Differential mounting and independent rear springing presented a frame problem solved by the design of a tubular backbone type of frame, with double wishbone box section ends. This type of construction, in tests against standard X-frame constructions, developed from 140 to 400 per cent greater torsional rigidity, combined with a reduction in weight of approximately 30-40 per cent, said Mr. Probst.

"One of the most interesting features of this unique departure from conventional design is the saving of some 40 lb. in unsprung weight in the front and 100 lb. in the rear as compared with a standard 3000 lb. sedan.

"Mr. Probst stated that in the geometry of this car it has been possible to hold track variations in front to ⅜ in., with normal camber of 1 deg. changing to ½ deg. negative at full rebound. As to braking through the springs, as is necessary in this design, the entire system is found to be considerably more rigid than the standard car."

New England Names Marsden

William S. Marsden, resident automotive engineer in Boston for the Ethyl Gasoline Corp., has been appointed secretary of the New England Section of the Society, succeeding R. R. Whittingham, who has moved out of the New England territory.

Additional S.A.E. Nominee for 1935

FOLLOWING publication of the S.A.E. nominees for 1935 on page 21 of the October, 1934, issue of the S.A.E. JOURNAL, the following additional nomination has been submitted to the Secretary by a Special Professional Activity Nominating Committee for insertion on the official ballot. This Committee was organized in accordance with the provisions of Paragraph C 47 of the constitution and Paragraph B 27 of the By-laws of the Society.

For Vice-President

Transportation and Maintenance .... Fred C. Patton
Assistant General Manager, Los Angeles Motor Coach Co.

The members comprising the Special Activity Nominating Committee which submitted this nomination were: H. W. Drake, E. C. Wood, Robert N. Reinhard, R. W. Moore, Lawrence J. Grunder, W. H. Fairbanks, G. A. Collender, M. P. Brooks, W. E. Powelson, E. E. Tattersfield, C. H. Jacobsen, Eugene Power, Gene E. Etzler, Joseph P. Seghers, A. R. Trombly, P. A. Wickes, J. Verne Savage, S. C. Schwarz, John G. Holmstrom, D. F. Gilmore, George E. Bock, Vernon A. Smith, C. H. Bolin, H. W. Musiel, Prof. Arthur B. Domonoske, Ulysses A. Patchett.

Observations of Flame in an Engine

By Charles F. Marvin, Jr.
National Bureau of Standards

DURING an investigation conducted at the Bureau of Standards under the sponsorship of the National Advisory Committee for Aeronautics, visual and photographic observations were made of the spread of flame to all parts of the combustion chamber of a single-cylinder L-head engine. Heads equipped with a large number of small windows symmetrically distributed over the combustion chamber were observed through a stroboscope, flame diagrams being obtained for a wide range of engine-operating conditions and for a variety of fuels, combustion-chamber shapes, and arrangements of single and twin ignition.

In this paper, the major factors influencing flame movement in the engine are discussed and their effects upon the diagrams are indicated.

As a means of studying more intensively conditions in and behind the flame front, measurements were made of the variations in intensity and spectral distribution of the infra-red radiation emitted through selected windows during normal and knocking explosions. The character of this radiation indicates that it is emitted almost exclusively by the final reaction products, water vapor and carbon dioxide, and the variations in its intensity show that reactions producing these substances continue in a normal explosion of 20 deg. or more of crank angle after inflammation of an element of charge. In those portions of the charge where fuel knock occurs, the reactions appear to be much more rapid.

CONCERNING flame movement, observations made through transparent windows in the heads of spark-ignition engines have shown that, during an explosion, a luminous zone originates at the spark plug and spreads rapidly throughout the combustion chamber until the entire charge is inflamed, the whole mass of gas continuing to glow for some time after flame propagation is complete.

Apparatus and Procedure

Some time ago, apparatus[1] was set up at the National Bureau of Standards under sponsorship of the N.A.C.A., which made it possible to follow the spread of the flame to all parts of the combustion chamber of an engine during operation, and thus to investigate the effects of engine operating-conditions, fuel characteristics and combustion-chamber geometry upon flame movement and velocity. This apparatus is shown diagrammatically in Fig. 1. The engine was equipped with a special head in which numerous small windows were symmetrically distributed over the combustion space. The head was observed through a stroboscope, which permitted a momentary view of the windows at the same point in successive cycles. By varying the timing of the view, it was possible to follow visually the progress of the flame as it spread from the spark plug to all parts of the combustion space. The function of the lens *C* was to

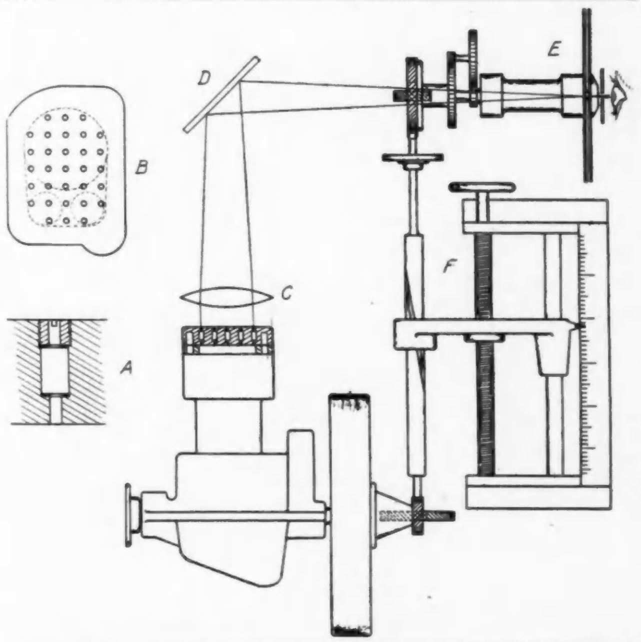


Fig. 1—Apparatus Used in Studying Flame Movement

Special engine heads with numerous windows are observed through a stroboscope, which permits a momentary view at the same point in successive cycles. By changing the timing of the view, the progress of the flame can be followed.

A=Detail of Window — *D*=Mirror
B=Plan View of Head — *E*=Stroboscope
C=Lens — *F*=Phase-Changing Device

[This paper was presented at the Semi-Annual Meeting, Saranac Inn, N. Y., June 21, 1934.]

[1] See N.A.C.A. Technical Report No. 399.

give the optical effect of looking straight down through each of the windows from a single position of the eye.

The progress of the flame was also observed photographically by placing a small camera at the eyepiece of the stroboscope as shown in Fig. 2, and making a series of time exposures at various fixed settings. The stroboscope thus acted as a high-speed shutter for the camera, exposing the film to the same phase of successive cycles. The camera shutter was left open long enough—about 30 sec.—to get a strong impression of the flame. In making these pictures a cardboard mask was placed over the head to show the outline of the combustion chamber and the positions of valves and piston.

Fig. 3 is a typical series of photographs. Each exposure is a composite picture of the same phase of about 250 explosions. Thus, picture 1 was taken 12 deg. before top dead-center or 8 deg. after the occurrence of the spark. The spark plug—with the wire leading to it—is shown over the left edge of the piston. In picture 1, the first trace of flame is visible in the window to the left of the spark plug. In picture 2, taken 4 deg. of engine-crank rotation later, the flame has spread to several other windows and, in successive pictures of the series, it continues to spread and increase in brightness until the whole combustion chamber is inflamed. About 36 deg. of crank travel or 0.006 sec. —at 1000 r.p.m.—was required for complete inflammation.

[2] See N.A.C.A. Technical Report No. 305.
[3] See N.A.C.A. Technical Report No. 280.
[4] See N.A.C.A. Technical Report No. 399.

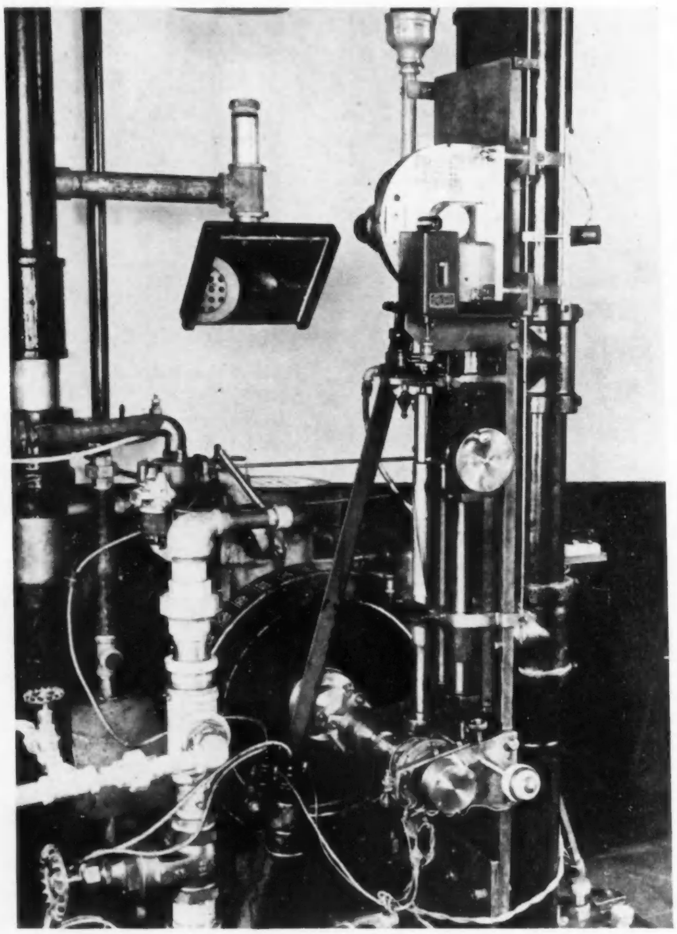


Fig. 2—Set-Up for Photographing Windows

A small camera, placed at the eyepiece of the stroboscope, is used to check the visual observations.

Visual and photographic observations of the arrival of flame in the windows may be converted into the type of diagram shown in Fig. 4, where the position of the flame front is indicated at successive 5-deg. intervals after the occurrence of the spark.

Flame Velocity in Space

Diagrams like that in Fig. 4 have been obtained for a wide range of engine operating-conditions, for diverse fuels, for combustion chambers of different shapes and for several arrangements of single and twin ignition. The outstanding feature of these diagrams is not their variety but their similarity, considering the range of operating conditions covered. In most of them the flame front advances in a pattern roughly concentric about the point—or points—of ignition, the chief differences being in the velocity of spread.

Flame velocities vary not only from one diagram to another but they are constantly varying from instant to instant and from point to point in the combustion chamber during a single explosion. Since many factors operate more or less independently but simultaneously to influence these instantaneous velocities, and since one or another of these factors may predominate depending upon operating conditions, it is very difficult to make generalizations or to isolate and evaluate with certainty the effects of individual factors upon the observed movements. However, the major factors which might be expected to affect flame movement will be enumerated and their apparent effects on available diagrams discussed.

In reviewing these factors it must be recalled that the velocity of the flame front in space—like that of a man walking along a moving car—is the sum of the rate at which the reaction advances into the unburned charge plus the rate at which the gases supporting the reaction are themselves moving through space. For convenience, these two components of the flame's observed velocity will be designated as "reaction velocity" and "gas velocity" respectively. It will be noted that the reaction velocity is the linear velocity at which the flame kindles the unburned charge, while the gas velocity merely expresses gas motions and involves no burning.

Reaction Velocity

The reaction velocity at which a flame front will advance into a quiescent mixture of fixed composition at constant temperature and pressure is constant and reproducible as has been demonstrated by the late Prof. F. W. Stevens in his experiments with soap bubbles blown with explosive mixtures. In these experiments, which are being continued at the National Bureau of Standards, it was found that the reaction velocity varies greatly for different fuels[2], is a maximum at or near the equivalent mixture for any given fuel, and is usually reduced by the presence of inert gases[3].

An example of the effect of different reaction velocities upon flame travel in the engine is shown in Fig. 5, where equivalent mixtures of methane, a slow-burning fuel, and ethylene, a fast-burning fuel, are compared. The general pattern of spread is the same for both, but speeds are higher throughout for ethylene.

A departure from optimum mixture ratio or an increase in the percentage of residual gases has been found to reduce flame velocities in the engine, probably through a reduction in both reaction velocity and gas velocity, although these separate components cannot be isolated in the experimental data[4].

Professor Stevens found that reaction velocities were unaffected by change in pressure[5] over a considerable range, and no significant effect of pressure has been detected in flame diagrams[6] for the engine or for a constant-volume bomb.

Although the temperature of the unburned charge just ahead of the flame front is expected to influence reaction velocity, its effects upon available flame diagrams for engines are so confused with simultaneous effects of other operating variables as to render conclusive interpretation impossible. There are indications of rather small and gradual increases in flame speed as temperature rises, but no signs of a pronounced effect have been found on any of the diagrams for normal explosions. It is believed that variations in charge temperature below the point where pre-flame reactions become pronounced have a rather minor effect upon flame velocities in the engine; but, above this point, variations may have a pronounced effect, and charge temperature probably becomes an important factor in determining the occurrence of fuel knock.

Fig. 6 shows diagrams for two different engine speeds, one double the other. Care was taken to meter into the cylinder the same weights of air and fuel per cycle in both cases; spark advance was the same; measurements with a balanced-diaphragm indicator showed equal pressures at ignition; and throughout the combustion, relative positions of piston and flame remained about the same for both diagrams. In each case somewhat more than 40 deg. of engine-crank rotation was required for complete inflammation which means, of course, that the flame traveled twice as fast at the higher engine speed, presumably because of greater turbulence. However, the type of turbulence effective here is obviously not a general gas movement; it does not carry the flame front with it, and thus increase the gas-velocity component. Rather, it appears to be a very local stirring of the molecules in the immediate neighborhood of the flame front which increases reaction velocity, presumably by facilitating collisions between burned and unburned materials and between oxygen and fuel molecules.

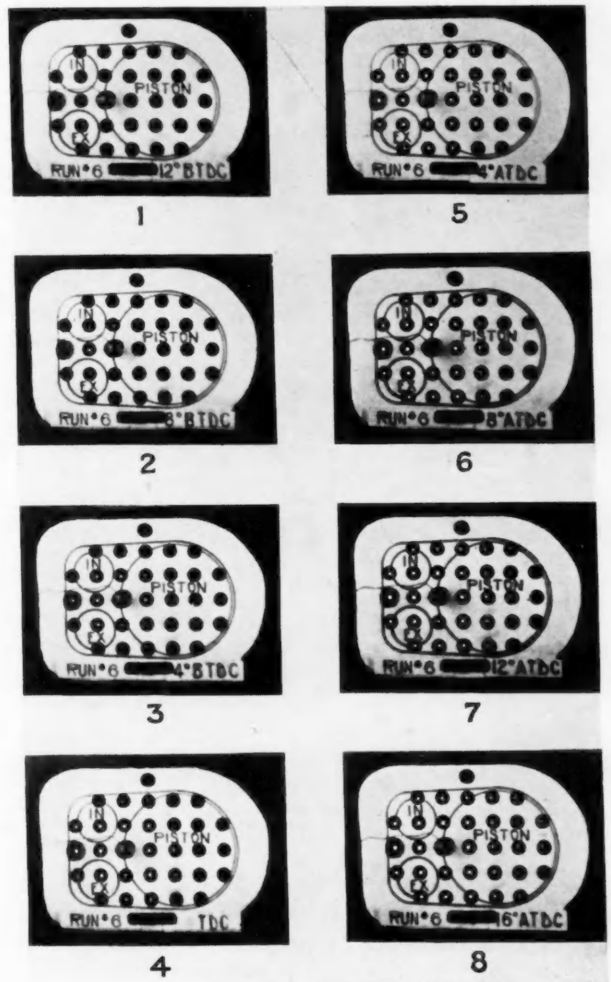


Fig. 3—Typical Photographs Showing Progress of Inflammation

The spark plug—with wire attached—is just over the left-hand edge of the piston. The spark advance was 20 deg., and picture 1 shows the first trace of flame in the window to the left of the plug. Succeeding pictures show the spread of flame to all parts of the combustion chamber.

Gas Velocity

The distortion of the diagrams of Fig. 6, as though a general swirl had carried the flame front forward on one side of the combustion chamber and retarded it on the other, is characteristic of all diagrams obtained with the spark plug in the position shown, although the direction of rotation is frequently reversed. With the spark plug at other locations, the distortion is sometimes noticeable but seldom pronounced. No rational explanation has been found to account for its erratic behavior, but it would seem that this lack of symmetry could be due only to a general rotary motion of the charge, set up by an unknown cause, or to local regions of high temperature or unfavorable charge composition, which, for obscure reasons, shift from one side of the combustion chamber to the other.

Many published flame records of individual explosions, in bombs and tubes particularly, show that gas velocity may be influenced by gas vibrations and wave effects. However, these effects are not detected in the average diagrams for many explosions as obtained by stroboscopic methods.

Movements of the piston, if sufficiently large, apparently affect gas velocity. Fig. 7 shows two diagrams made with the spark plug at opposite ends of the combustion chamber, but otherwise under similar conditions. The spark advance was 10 deg., so the flame front was only a short distance from the spark plug when the piston started downward. The rush of gas to occupy the volume displaced by the piston carried the flame front forward when the spark plug was over the valves as at *A*, but it blows against the flame when the spark plug is over the piston as at *B*, decreasing gas velocity and prolonging the inflammation period about 10 deg.

The burning process itself also sets up gas movements. In a so-called constant-volume explosion, each increment of charge overtaken by the advancing flame front is burned, not at constant volume but more nearly at constant pressure, and it therefore expands to an extent dependent largely upon the temperature rise for the reaction. When an increment of charge expands in the flame front, it compresses both the unburned charge ahead and the previously burned charge behind, the amount of movement in each direction being approximately proportional to the relative volume of gas in that direction. The effect of this expansion in a nonsymmetrical container is to carry the flame front most rapidly toward the greatest volume of unburned gas. In the domed combustion chamber shown at *A*, in Fig. 8,

[5] See N.A.C.A. Technical Report No. 372.
[6] See N.A.C.A. Technical Report No. 399.

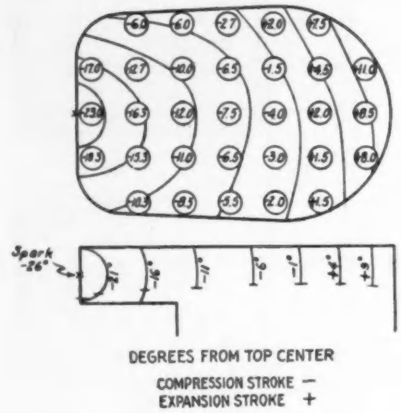


Fig. 4—Typical Flame Diagram. The Position of the Engine Crank When Flame Arrives Under Each of the Windows, as Determined from Photographs or Visual Observations, Is Used in Estimating the Position of the Flame Front at Successive 5-Deg. Intervals after Occurrence of the Spark

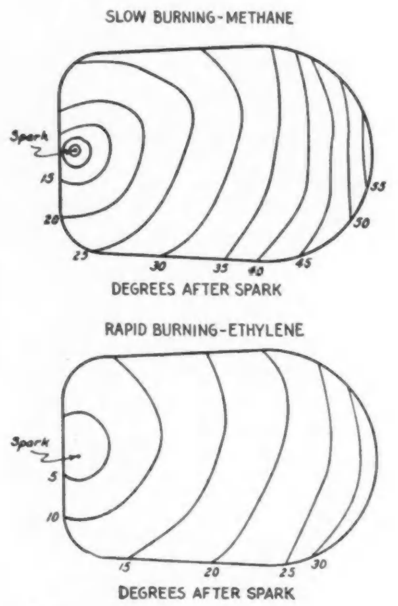


Fig. 5—Effect of a Difference in "Reaction Velocity", That Is, Linear Rate of Advance of the Flame Front into the Unburned Charge

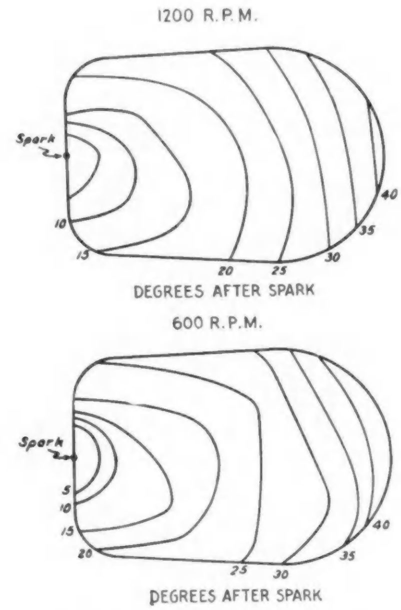


Fig. 6—Flame Velocities Are Nearly Proportional to Engine Speed; So, the Time Required for Complete Inflammation of the Charge, Expressed in Degrees of Engine-Crank Rotation, Remains Nearly Constant Over a Wide Range of Speeds

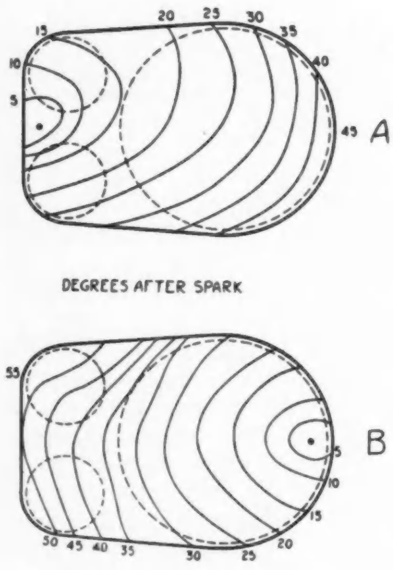


Fig. 7—Mass Movements of the Gases Influence Flame Velocities in Space. With a Retarded Spark, the Rush of Gas To Fill the Space Vacated by the Receding Piston Carries the Flame Front Forward in *A* But Retards Its Advance in *B*

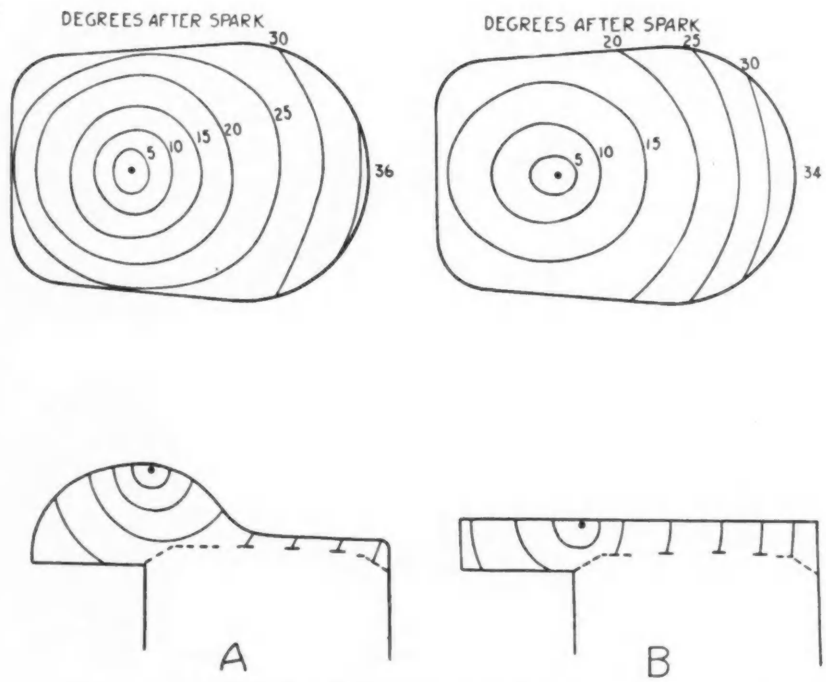


Fig. 8—Expansion in the Reaction Zone Sets Up Gas Movements Which, in General, Tend To Carry the Flame Front Most Rapidly Toward the Greatest Volume of Unburned Gas

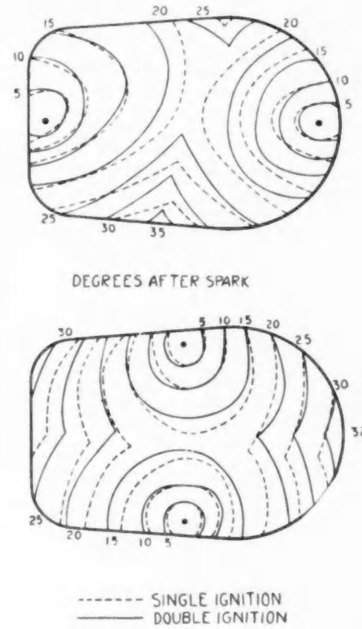


Fig. 9—With Double Ignition, "Reaction Velocities" Are Probably Greater Than with Single Ignition But Gas Movements Contribute Less to the Advance of the Flame Front. Apparently, One or the Other of These Factors May Predominate, Depending upon Operating Conditions

volume is pretty well concentrated around the spark plug; there are no remote regions of large volume to attract the expanding gases, and the flame spreads at a nearly uniform and relatively low speed in all directions. With the flat combustion chamber *B*, there is little room for vertical movement and expansion tends to move the gases horizontally, particularly toward the ample volumes at either end of the chamber, the result being somewhat higher flame speeds and a more eliptical pattern of spread. Less active local turbulence in the domed combustion chamber might be a contributing cause of the lower flame speeds consistently observed in this type of head.

In Fig. 9, the progress of the flame with double ignition —represented by the solid lines—is compared with the progress when each plug is fired separately as shown by the dotted lines. With double ignition, expansion of the gases within each flame front is resisted by compression from the opposite flame, with the result that gas velocities are lower than with either plug firing separately. However, for a given position of the flame front, the temperature of the unburned charge will be greater when it is compressed from two directions at once; hence, higher reaction velocities might be expected with double ignition. Apparently, either of these effects may predominate in determining flame speed in space, depending upon operating conditions. In *A* of Fig. 9, flame speeds are slightly higher for single ignition. In *B*, differences are not so consistent but tend to favor twin ignition. Higher flame velocities with double ignition are also shown by a comparison of two flame diagrams obtained by Schnauffer[7].

If it is assumed that reaction and heat liberation are confined to the flame front, the contribution of expansion to the flame's velocity will be a maximum just after ignition, for only at this point will the full expansion be effective in carrying the flame front forward. Obviously, the extent to which the expansion can push the flame ahead will decrease as the flame advances and gas velocity will decrease to a limiting value of zero as the flame arrives at any wall. Simultaneous with the decrease in gas velocity, there is an increase in reaction velocity as the temperature of the unburned charge rises, the net result being to minimize variations in the velocity of the flame in space during inflammation.

A few diagrams show a nearly constant velocity throughout the inflammation period. However, the great majority exhibit low initial velocities, increasing velocities during the early stages, and decreasing velocities near the end of the inflammation period as shown in Fig. 10. The diminishing velocities as the flame approaches the far wall in a normal explosion show that the increase in reaction velocity resulting from the rise in charge temperature is insufficient to offset entirely the decrease in gas velocity, even in the later stages of the explosion where the greatest effects of rising temperature would be anticipated. It seems improbable, therefore, that rising charge temperature could increase reaction velocity by a sufficient amount to overshadow so completely a decrease in gas velocity in the early stages. Rather, it would seem that the anticipated decrease in gas velocity does not occur in the early stages. If burning is not confined to the flame front, but continues in an element of charge for a considerable period, the effect would be to delay and reduce the anticipated contribution of expansion to the flame's velocity and produce the low initial velocities observed. Additional evidence that the reaction zone has a considerable and varying depth in the engine is found in the fact that indicator diagrams[8] show heat liberation to continue for considerable and varying periods after flame diagrams show complete inflammation.

Radiation

As a means of investigating more intensively conditions in and behind the flame front, measurements[9] were made of the variations in intensity and spectral distribution of the radiant energy emitted through selected windows in the head as the flame passed under them.

Apparatus.—For these experiments, the apparatus was modified as shown in Fig. 11. Observations were made in a window close to the spark plug (No. 6) and in one at the opposite end of the combustion chamber (No. 30). A disc of fluorite, transparent in the infra-red to about 11 μ, was used as a window, and the beam of radiation was reflected and focused by surface-silvered mirrors onto the slit of the stroboscope. The divergent beam on the opposite

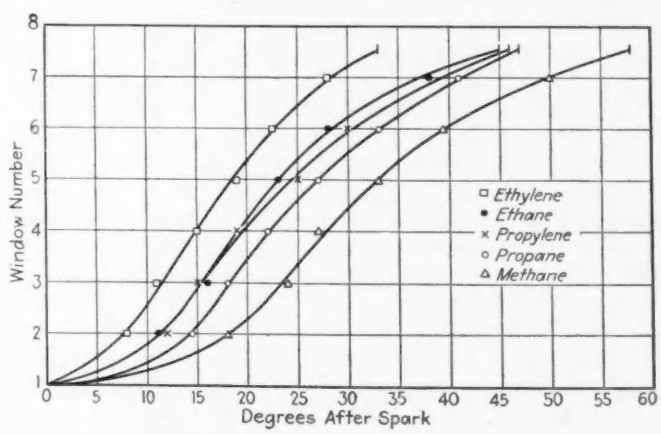


Fig. 10—Progress of the Flame Front Down the Center of the Combustion Chamber. Most of the Flame Diagrams Show Relatively Low Velocities Early and Late in the Inflammation Period

[7] See S.A.E. JOURNAL, January, 1934, p. 22; Figs. 16 and 17.
[8] See N.A.C.A. Technical Report No. 399.
[9] See N.A.C.A. Technical Report No. 486.

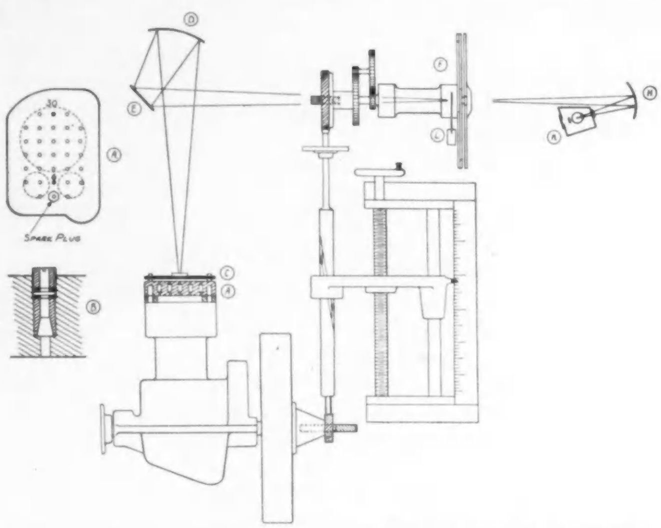


Fig. 11—Apparatus Used in Measuring Radiant Energy

Radiation from a selected window is reflected and focused through the stroboscope and onto a highly sensitive thermocouple for measuring its intensity.

A—Head with Windows
B—Detail of Fluorite Window
C—Radiation Shield and Filter
D, *E* and *H*—Surface-Silvered Mirrors
F—Stroboscope
K—Thermocouple
L—Shutter

side was reflected and focused by another mirror onto the target of a single-junction antimony-bismuth vacuum thermocouple. Thermocouple electromotive force was measured by a potentiometer method, using a sensitive Thompson galvanometer as a null instrument.

Filters for determining spectral-energy distribution were placed over the window on a radiation shield mounted over the engine head.

A balanced-diaphragm pressure-indicator with a timing contact operating in synchronism with the stroboscope discs make it possible to measure the instantaneous cylinder pressure corresponding to each radiation reading, or to make a complete indicator diagram if desired.

Theory.—Before presenting the results obtained, it might be well to review briefly the theoretical considerations which dictated the procedure followed. According to the literature on the subject, a very high percentage of the radiant energy from hydrocarbon flames is in the infra-red and is emitted almost exclusively by incandescent carbon and newly formed molecules of carbon dioxide and water vapor.

Fig. 12 shows typical emissions for these three substances plotted against wave length. Incandescent carbon radiates like a black body, the spectral distribution of its radiation varying with temperature as shown at *A*. At temperatures existing in flames, the bulk of the energy from incandescent carbon would appear in the region between 1 and 2 μ. This is demonstrated in the spectrum *B* for a brilliant acetylene flame in which radiation from the carbon simulates very closely that for a black body at 2500 *K*. The intense band of radiation between 4 and 5 μ, seen in *B*, *C* and *D*, is characteristic of carbon dioxide, neither of the other substances radiating appreciably in this region. Radiation from H_2O is more scattered. A prominent band appears at about 2.8 μ, but CO_2 also has a band in the same region. However, water vapor emits on numerous bands—not prominent in the diagram—scattered beyond 5 μ in a region where energy from the other radiators is negligible. Thus, each of the three principal radiators has a radically different characteristic spectral distribution.

Fig. 13 shows the transmissions of five filters which were selected to isolate as far as possible the prominent emissions of the three substances of interest. Thus, filter *F*, of fluorite, is very transparent to the radiation from water-vapor beyond 5 μ, while filter *E*, of microscope-cover glass, is only slightly so. Similarly, filter *E* passes radiation from the prominent CO_2 band between 4 and 5 μ, while the quartz filter *D* does not. Radiation from incandescent carbon is largely concentrated in the regions covered by filters *B* (pyralin) and *C* (red glass), the relative amounts of energy appearing in these two regions varying with the temperature of the carbon.

Spectral Distribution.—Fig. 14 illustrates a graphical method of interpreting relative readings through the filters directly, in terms of the relative intensity of the radiation from the three constituent radiators in a composite flame. If a flame burning CO, and thus producing only CO_2 as a combustion product, is observed through each of the filters in turn, and if the energy transmitted by each is expressed as a percentage of the energy transmitted by the fluorite, the result will be a series of values, arbitrary to be sure, but nevertheless exactly characteristic of the spectral distribution of radiation from CO_2. Such a set of values is plotted on the right-hand edge of the prism. Quite a different set will

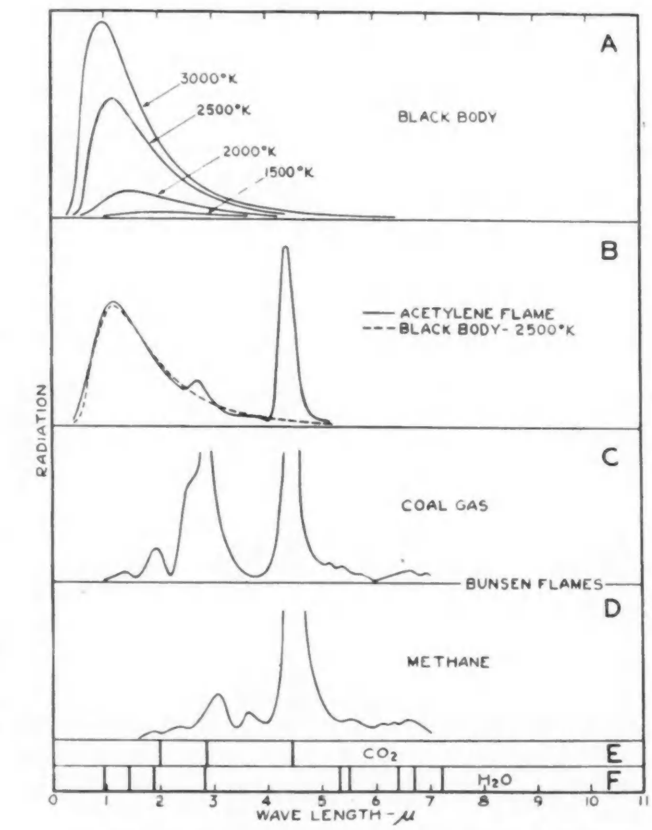


Fig. 12—Typical Spectra Showing Characteristic Emissions from Incandescent Carbon, Carbon Dioxide and Water Vapor

A—Black-body radiation, characteristic of incandescent carbon
B—Acetylene flame showing emissions from carbon (peak near 1 μ) and from CO_2 (peak near 4.5 μ)
C and *D*—Non-luminous flames showing emissions from CO_2 and H_2O
E and *F*—Scales indicating locations of more prominent maxima in CO_2 and H_2O spectra.

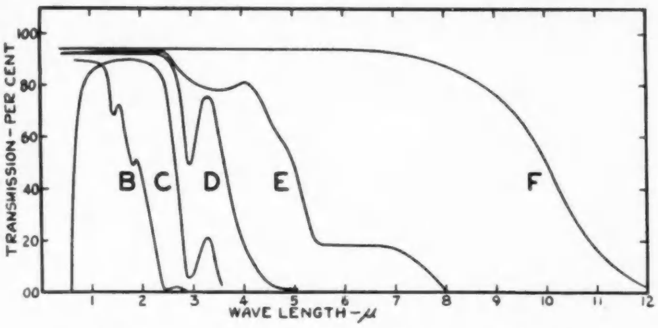


Fig. 13—Transmissions of Filters Selected To Isolate As Far As Possible, without the Use of a Spectrograph, the Prominent Emissions of the Three Principal Radiators

B—**Pyralin** *E*—**Microscope Cover-Glass**
C—**Red** *F*—**Fluorite**
D—**Quartz**

be obtained if a hydrogen flame, producing only H_2O as a product, is observed. Such a set appears on the forward edge of the prism.

Similarly, a series of values characteristic of the radiation from incandescent carbon at a temperature of 2500 *K* is plotted on the left edge of the prism. On each edge there is thus a value for each filter, the three points for any given filter defining a plane which cuts through the prism. Each plane constitutes a locus for all values which would be obtained with the corresponding filter in observing composite flames in which the three constitutent substances radiate with varying relative intensities. Thus, each vertical line piercing the prism will represent a composite flame, its spectral distribution being defined in terms of relative filter readings by the intercepts of the several planes on the line, and the relative intensity of the radiation from its three constituent radiators will be shown by the proximity of the line to their respective axes on the edges of the prism.

In analyzing a flame, for example that for city gas in a Bunsen burner, the observed amounts of energy passed by the several filters are expressed as percentages of that passed by fluorite and are plotted on a strip to the scale shown on the right in Fig. 14. This strip is then located on the diagram where the plotted points show the minimum total deviation from the planes for the corresponding filters. In the case of the Bunsen flame for city gas, the strip fits best on a face of the prism.

The top plane of the prism in Fig. 14 is a plot on triangular coordinates of the relative intensity of the radiation from the three primary radiators, the apex for each radiator being 100-per cent intensity and the opposite edge, zero intensity for that radiator. Thus, the analysis for the radiation from the city-gas flame is: zero energy from carbon, 70 per cent from CO_2 and 30 per cent from H_2O. Strips representing widely different conditions in the engine are grouped together near the H_2O axis of the diagram.

The application of this type of analysis to radically different flames demands that the spectral distributions for the primary radiators remain essentially constant over a wide range of flame temperatures, depths, densities and pressures, and that radiation from other substances and selective absorption be negligible. The fact that most of the flames examined can be fitted to the diagram with very small deviations is circumstantial evidence, but by no means conclusive proof, that these conditions are met in the majority of cases. Additional observations through the filters of burner and engine flames using as fuels hydrogen and carbon monoxide separately and in known mixtures would provide the basic data for much more certain and adequate interpretation by this method. Meanwhile, conclusions must be drawn with caution and about all that can be said with assurance is that, over a wide range of conditions, spectral distributions for the engine flames are roughly similar, exhibiting strongly the characteristic emissions of CO_2 and H_2O while radiation from incandescent carbon is relatively very weak.

"Total" Radiation.—Since the final reaction products, H_2O and CO_2 are the chief sources of radiation in the engine flame, an increase in the total radiation would be expected to accompany the formation of these materials in or behind the flame front. Variations in total radiation—through fluorite—for a normal run in both windows (Nos. 6 and 30), and for a knocking run in the window opposite the spark plug (No. 30) are plotted in Fig. 15, which shows also the corresponding variations in pressure. In all cases radiation begins to rise upon the appearance of visible flame, and continues to rise for a considerable period thereafter.

This increase in radiation can occur only so long as the number of radiating molecules under the window is increasing at a sufficiently high rate to more than offset the effect of the rapid cooling which all newly produced molecules

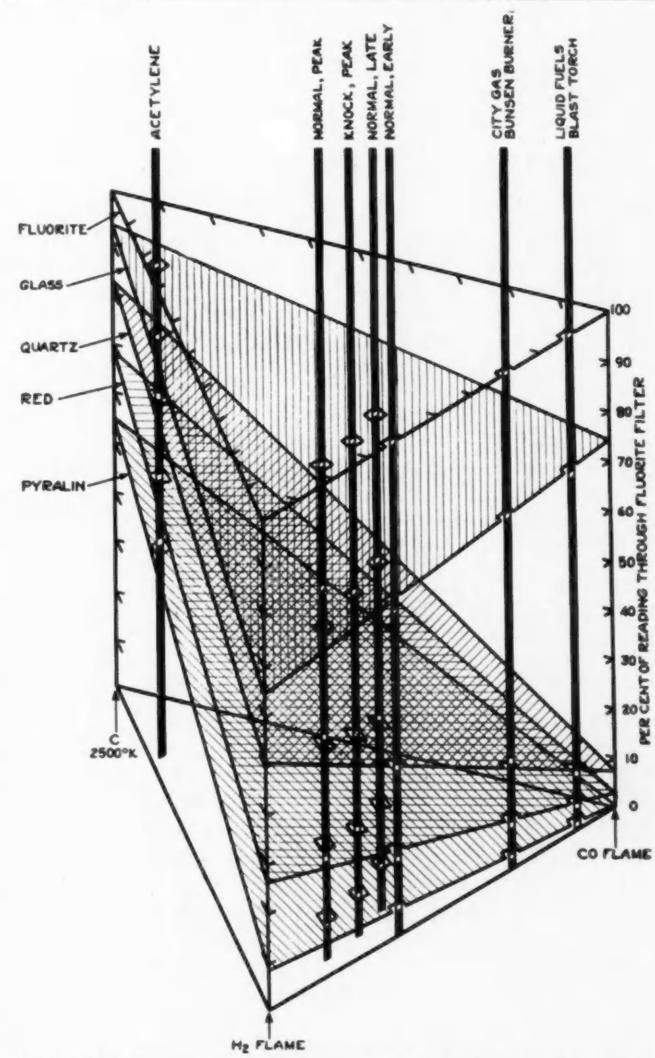


Fig. 14—Graphical Method of Analyzing Observations Directly in Terms of the Relative Intensity of Radiation from the Three Principal Radiators in Hydrocarbon Flames

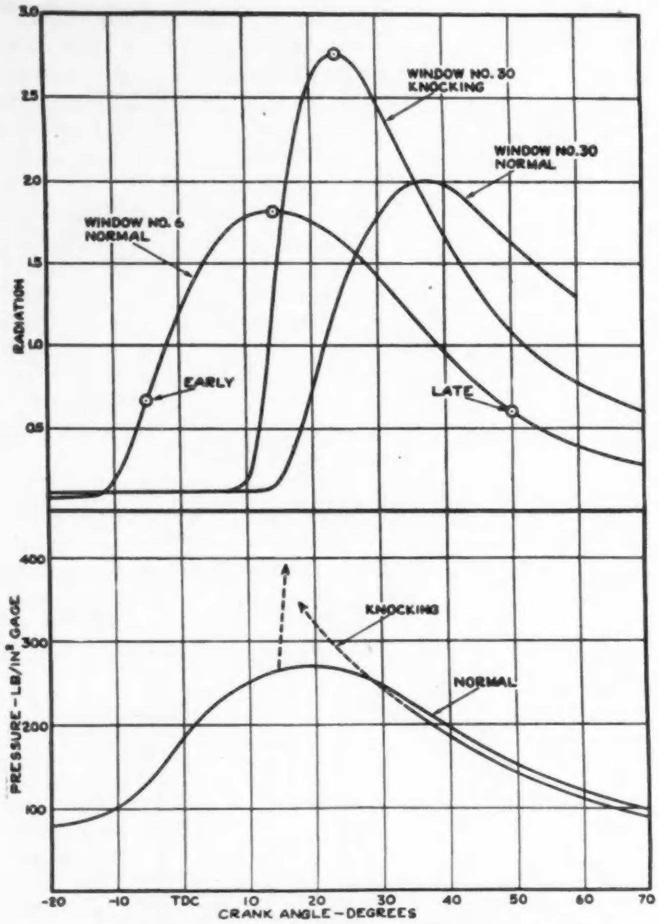


Fig. 15—Variations in Radiation and Pressure During Normal and Knocking Explosions

Radiation starts to increase when the visible flame arrives under a window and continues to rise for a considerable period thereafter. The duration of the rise is shorter in that portion of the charge involved in fuel knock, indicating more rapid reactions.

must undergo immediately after formation. An increase in the number of molecules under a window can be brought about by (*a*) formation of new molecules, (*b*) compression of the gas, or (*c*) increase in the depth of the column observed. Since the piston is moving downward during burning in window No. 30, there will be an increase in the depth of the column of gas observed which, however, is largely offset by the accompanying decrease in its density, the small net gain in molecules due to piston movement alone being entirely inadequate to offset the cooling effect, as is demonstrated by the steep descent of the curve beyond its peak. The fact that total radiation for a normal explosion increases in window No. 30 for about 20 deg. of crank travel after the arrival of the flame, can therefore only mean that reactions producing H_2O and CO_2 are continuing for at least this period, and probably longer, after inflammation.

Under window No. 6, the expansion accompanying the arrival of the zone of most rapid reaction is followed by recompression as the zone proceeds through the remainder of the charge. This recompression is accompanied by a movement under the window of charge driven back toward the spark plug by the continued expansion in the advancing zone. Thus, the element of charge which is observed when radiation is a maximum is not the same element which was observed at inflammation but one which the flame reached later in its travel. These conditions probably account for the somewhat longer period of increasing total radiation in window No. 6, 25 deg. as compared to 20 deg. in window No. 30 where there is no recompression and little gas movement.

During fuel knock, flame appears earlier in the region remote from the spark plug and radiation reaches a maximum much sooner after the appearance of flame. This indicates not only earlier ignition of the last portion of the charge to burn, but more rapid reaction following inflammation than in the normal type of burning.

Measurements of total radiation thus provide a means of investigating the effect of engine-operating conditions on the depth of the reaction zone behind the flame front and the duration of combustion in a given element of charge. Further development of the method would doubtless reveal other uses.

Discussion of Slonneger Paper

Because of errors which appeared in the original presentation of the following material on page 347 of the September issue, this discussion of the paper by J. C. Slonneger entitled "Effective Combustion as Determined from the Indicator Diagram" (published in the S.A.E. JOURNAL *for August, 1934) is herewith reproduced in full.*

Heat Required Varies with the Crank Angle

—H. C. Gerrish

National Advisory Committee for Aeronautics

MR. SLONNEGER'S method of indicator-diagram analysis depends upon the assumption that the "heat required to increase the power curve from one polytropic curve to the next is a constant and independent of the path." This assumption is contrary to accepted thermodynamics, which considers that the total heat input is a function of the path. It would be interesting to know just how Mr. Slonneger's method takes into account the heat utilized in performing work.

Mr. Slonneger's method assumes that it requires the same amount of heat to go from a given polytropic to another at small crank-angles as it does at large crank-angles. Fig. 3 is presented for the purpose of showing the effect of the author's assumption on the amount of heat involved. It shows the ratio of the heat required at any point to the heat required at top center to go from a given polytropic to another very close to it. It will be seen that the heat required in going from one polytropic to another varies with the crank angle.

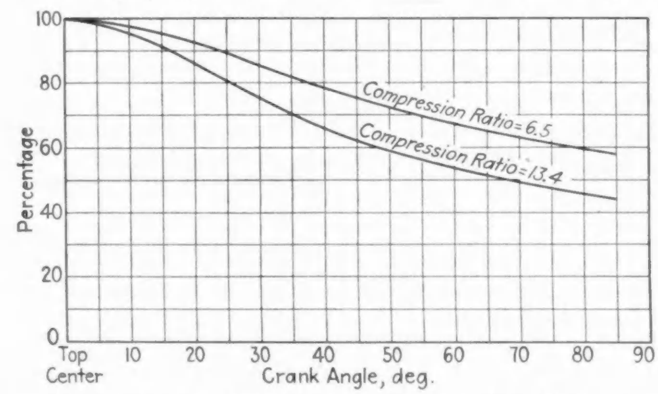


Fig. 3—Ratio of the Heat Required at Any Point to the Heat Required at Top Dead-Center To Go from a Given Polytropic Curve to Another Very Close to It

Butane as an Automotive Fuel

By D. P. Barnard
Research Department, Standard Oil Co. (Ind.)

RECENT active interest in the use of commercial butane gas as a fuel for highway-transportation equipment, particularly on the Pacific Coast, indicated to Mr. Barnard the advisability of resurveying the field of possible substitutes for gasoline, especially as regards butane.

Since rapid developments in the conversion of truck fleets to use butane as fuel took place in the West, Mr. Barnard considers the possibility of the general use of butane in this class of service.

After going into detail regarding the chemical properties and performances of butane and gasoline, as well as their economic aspects, Mr. Barnard concludes that an attempt to supply butane under the conditions necessary for highway units eventually would result in a final cost to the operator—on a gallonage basis—higher than that prevailing for regular gasoline. He states that no very widespread use of butane as a fuel could occur without increasing the demand to a status at which the cost would be prohibitive.

IN the operation of any industrial or transport automotive equipment economy in all of its phases is a prime factor affecting the suitability of any particular item involved. This must necessarily be true of any operation of a competitive nature. The net result is that the builders and operators of transport equipment and industrial engines are always interested in the possibilities of reducing fuel costs, particularly as this item represents a very important part of the total cost of operating the equipment.

This interest in reducing fuel costs manifests itself not only in attempts to get the largest possible amount of useful work from each gallon of gasoline consumed, but also in active interest in the possibilities of using fuels other than gasoline. This is particularly true in the case of fuels whose present status is that of a by-product, as the hope is that these materials might be available at prices which will permit reductions in fuel costs. To a certain extent the interest shown in substitutes for gasoline results, not from the fact that gasoline itself is a poor fuel or one which cannot be used economically, but rather from the fact that its principal use is in passenger-car equipment where the fuel-economy feature occupies a position very decidedly subordinate to such performance requirements as acceleration, smoothness, and reliability under all conditions.

The ordinary passenger automobile operates at an overall thermal efficiency which is quite low, it being doubtful if in any case this figure averages more than 7 per cent, with ton-mileages not greatly exceeding 20 ton-miles per gal. However, the fact that quite high economies along with mileages well in excess of 100 ton-miles per gal. of gasoline are regularly obtained with modern highway-transportation equipment can be taken as an indication that gasoline is, after all, not so bad. Nevertheless, due to the prime importance of fuel economy in this class of service, it is always good policy occasionally to resurvey the field of possible substitutes. The recent active interest in the use of commercial butane gas in transport work, particularly on the Pacific Coast, indicates the advisability of such a study at this time.

The use of butane as a highway fuel started on the Pacific Coast where, apparently, it was available in appreciable quantities and where it was being put to no particular use. Evidently, the assumption was made that this material was virtually valueless at the refinery and should either be given away or at least sold at a very low price; consequently, some very rapid developments in the conversion of truck fleets to use this fuel took place. In the following discussion, an attempt is made to develop the possibility of the general use of butane in this class of service. To complete the picture, however, several possible fuels derived from petroleum and included in Table 1 are given with their more important general characteristics.

In all cases, values are approximate and slide-rule conversions have been employed. It may be found, therefore, from a close inspection that many second-order discrepancies occur. However, the values given will indicate quite accurately the general characteristics of the various fuels for purposes of comparison. In examining Table 1, it will be noted that butane in particular must be handled and stored under considerable pressure and that its specific gravity is quite low compared with the other petroleum fuels. Further, its optimum explosive limits in terms of percentage of vapor by volume in the mixture is definitely higher than in the case of other fuels. In this connection it might be well to point out that apparently an error has occurred in some articles describing butane gas in certain trade publications in which it is stated that only 1 part butane to 31 parts of air is required for the correct mixture, as against approximately 1 to 16 for gasoline. This error has apparently arisen through confusion of the volumetric limits on the one hand with weight proportions on the other.

One other outstanding characteristic of butane is its high knock rating, it being well up toward 100 and above that

[This paper was presented at the April 3, 1934, meeting of the Chicago Section.]

Table 1—General Characteristics of Butane and Gasoline

	Butane (Commercial)	Gasoline Aviation	Gasoline Motor
Initial Boiling Point, deg. fahr.	...	120	100
10 per cent evaporated, deg. fahr.	...	145	140
90 per cent evaporated, deg. fahr.	25	220	350
Percentage at 392 deg. fahr.	...	...	...
End Point, deg. fahr..	100	260	390
Vapor Pressure, lb. per sq. in.	65 (at 105 deg. fahr.)	7 (Reid)	8 (Reid)
Flash Point	...	...	...
Octane Number (CFR-Motor)	90 to 100	73 (<87)	70 (<76)
A.P.I. Gravity	113	70	60
Specific Gravity	0.58	0.70	0.74
Pounds per Gallon	4.8	5.84	6.15
Net Heat Content:			
B.t.u. per lb.	20,500	20,000	19,700
B.t.u. per gal.	97,500	117,000	121,000
Carbon, per cent	83-86	86	86
Hydrogen, per cent	17-14	14	14
Characteristics, C Group	C_4	C_6-C_7	C_7-C_8
Average Molecular Weight	56-58	90	108
Explosive Limits, percentage by volume:			
Lean	1.9	1.2	1.0
Rich	6.5	(6.0)	(6.0)
Optimum	3.1	2.3	1.72

of any other generally used fuel. A very casual survey of its low specific gravity, however, immediately suggests that *full advantage of this knock rating must be taken* to bring volumetric fuel economy up to values which would be comparable with those obtained with the heavier fuels.

The explosive-mixture-ratio data expressed in the terms ordinarily employed in automotive practice are given in Table 2. Here again it will be noted that butane forms mixtures slightly leaner than ordinary fuels on a weight basis. When these mixture ratios are converted into *gallons* of fuel necessary to make operating mixtures with a given volume of air, it is obvious that the lighter fuel shows up to a very decided disadvantage. This volumetric consumption disadvantage amounts to over 20 per cent when compared with motor gasoline, and must be overcome before actual realization of the benefits of higher compression and better volumetric efficiency than are possible with gasoline.

Table 3 gives results obtained when these data are corrected for full advantage of knock rating and high volatility to produce the best engine performance possible within customary construction and operating-cost limits. Again it will be noted that in spite of the 30 per cent possible increase in brake mean effective pressure and a reduction in specific fuel consumption of 15 per cent compared with the representative values for current practice with motor gasoline, butane still shows up at a disadvantage when fuel consumptions are considered upon a volumetric basis.

It would appear, therefore, that the only possibility in using butane for highway service, granting that the ultimate price of the fuel delivered to the consumer is not greatly below that of gasoline, would lie in improved performance of the equipment under certain driving conditions, reducing the necessity for gearshifting and thereby lowering the average swept engine-volume for a unit of distance of more than 8 per cent. It does not appear at this time that this possibility exists, particularly in the Middle-West, although it may be that some such effect as performance improvement has been of influence in the observations reported on the Pacific Coast.

To break even on fuel costs when using butane, it will be necessary that this product be available at a cost approximately 10 per cent less than the cost of gasoline. However, due primarily to the fact that transportation and handling costs of materials which must be kept under pressure are so much greater than those normally associated with gasoline, a substantially lower price on butane—when small quantities are considered—does not appear to be a very hopeful prospect. Further, the fact that any fuel used upon the highway must bear the full amount of State and Federal taxes tends to reduce the possibility of furnishing butane at a price lower than that of gasoline. In fact, at present, it appears that any attempt to supply butane under the conditions necessary for highway units eventually would result in a final cost to the operator—on a gallonage basis—higher than that prevailing for regular gasoline. Actually if there is any advantage to be gained in the improvement of performance of existing vehicles, aviation gasoline of the fighting-grade type would appear to be a more attractive ultimate possibility than butane.

In Table 3 is given a rough estimate of the final weights which would result if equipment were designed for each of the fuels under consideration. In the case of butane, pressure tanks for use on vehicles would be so heavy as to make the combined weight of the powerplant and tankage installed at least as heavy as in the case of gasoline. If the tanks be as small as 50 gal. in capacity, the weight would be definitely higher and even the lighter weight of the fuel itself would not completely offset the increase in tank weight.

It would seem that one very real possibility for the economic use of butane as an internal-combustion-engine fuel should exist in railway service for such equipment as high-speed railcars and, possibly, switching locomotives. In the case of the former, it is quite desirable to secure large power-outputs along with smoothness of operation and reasonably light weight. At the same time it is also desirable to avoid multiplicity of units such as would be required in case outputs of the order of 1000 hp. are to be attained with conventional gasoline engines.

For example, for this class of service there should be a demand for a moderately light-weight powerplant of from 800 to 1000 hp., which at the same time must operate at as low fuel cost as possible. The use of butane should greatly facilitate the design of a new engine. It is conceivable that an engine not greatly exceeding in displacement that of the

Table 2—Explosive-Mixture-Ratio Data

	Butane (Commercial)	Gasoline Aviation	Gasoline Motor
Air Fuel Ratio, by weight:			
Chemically Perfect Mixture	15.5	15.0	14.8
20-Per Cent Rich Mixture	12.4	12.0	11.8
Pounds of Fuel Per 120 Cu. Ft. of Air:			
Perfect Mixture	0.587	0.606	0.615
20-Per Cent Rich Mixture	0.705	0.728	0.738
Gallons of Fuel Per 120 Cu. Ft. of Air:			
Perfect Mixture	0.122	0.104	0.100
20-Per Cent Rich Mixture	0.147	0.125	0.120

Table 3—Approximate Possible Performance

	Butane (Commercial)	Gasoline Aviation	Gasoline Motor
Relative Brake Mean Effective Pressure, lb. per sq. in.	125	110	100
Relative Specific Consumption	83	94	100
Relative Volumetric Consumption	108	99	100
Relative Weight Per Horsepower:			
Excluding Tanks	80	91	100
Including Tanks	100-110	91	100

time-honored Liberty could be developed for this class of service and which, even with quite generously rugged construction, would not need to weigh more than 5 lb. per hp.

One very real advantage in developing an engine of this size for operation on butane is the very great simplification of the induction system, which has always been a very serious problem in connection with the large units of the carburetor type. Provided that the objection to fire hazard could be overcome, it would appear at first thought that such a powerplant would be better adapted to high-speed light-weight railcar-service than would the Diesel engine. Further, its operating costs probably would not be very much greater than those of the Diesel, provided that the butane could be handled in large enough quantities and at relatively few points. This latter requirement is an absolute necessity in the economical use of butane, as its distribution costs increase very markedly when it must be handled in small quantities.

As to the requirements for switching-locomotive service, here again it happens that butane might be quite a desirable fuel. In this work it is necessary to have available for immediate use a relatively large amount of stand-by power. Two butane-burning engines might be installed in the locomotive, the reserve engine being kept at normal operating temperature by interlocking of the cooling systems. Due to the fact that no warming up of the induction system is necessary when butane is used, the reserve engine would be ready to be put into use whenever a large power output was necessary. Such an arrangement would make possible quite good fuel economies and at the same time avoid any substantial decrease due to waiting for the reserve engine to assume its share of the load. Again it should be pointed out that the same objections as to fire hazards must be overcome, and the same requirements for distribution of fuel supply must be met, as in the case of the railcar.

In the foregoing consideration it does not appear that butane can be adapted economically to use in small units, particularly for highway service, as it does not offer appreciable cost advantages under these conditions. It is true that there are certain benefits such as reduced engine-maintenance costs, better performance with the existing equipment, and the like, which can be realized by conversion to butane. This latter advantage, however, is exactly equivalent to the installation of a larger powerplant and can only be accomplished in existing equipment at the expense of a very definite increase in total fuel costs unless more power is definitely necessary.

Butane possesses some disadvantages in addition to those of cost; in particular, that of fire risk, as the handling of such material under pressure definitely increases the hazard over that of handling gasoline. At present there are no regulations covering this point. But it is only fair to assume that, if its use should become widespread, new and rather drastic regulations might be put into effect which would of necessity increase the cost of equipment involved and the handling of the fuel.

Further, all of the butane carbureting systems which have been devised up to the present depend upon the vapor pressure of the fuel itself for their functioning. At 25 deg. fahr. the vapor pressure of commercial butane is less than atmospheric. This requires the use of auxiliary starting equipment such as the installation of a gasoline carburetor for cold-weather starting-purposes. Again, as has already been mentioned, the distribution costs involved in handling butane in relatively small quantities appear to be prohibitive at this time.

It would seem that, where the use of some other fuel than gasoline is indicated, butane may possibly be supplied, particularly in the case of large units as exemplified by the high-speed railcar and the switching locomotive, the supply being so located that transportation costs and handling problems may be reduced to a minimum. Further, it should be borne in mind that, in spite of some statements which have been published to the contrary, the amount of butane which can be economically recovered in the course of present refinery and natural-gasoline-plant operations is definitely limited, and that no very widespread use of butane as a fuel could occur without increasing the demand to a status at which the cost would be prohibitive.

Appendix

Table 4 shows the approximate amounts of commercial butane which are produced at present along with gasolines of current average composition. To keep within the vapor-pressure limits necessary to avoid undue vapor-lock difficulties (this corresponds to an average in excess of a Reid vapor pressure of 10 lb. per sq. in.) it is necessary to dispose of about 16 per cent of the total refinery butanes in other ways. This makes available for all of the various industrial uses about 8,000,000 bbl. annually, each of 42-gal. capacity, which amount is supplemented by natural-gas butanes. The total amount so available, however, would suffice for only about 10 per cent of all of the 3,000,000 commercial vehicles registered in 1933 and, even if all of the butanes existing in natural gas were to be recovered, the amount would still fall far short of possible commercial demands. These amounts should be ample, however, for any probable railcar or other railway demands for some considerable time to come.

Table 4—Production of Commercial Butane and Gasolines for 1932

	Production, 42-Gal. Bbl.
Total Refinery Gasoline[a]	399,524,000
Total Natural Gasoline[a]	35,750,000
Total Refinery Butanes	48,000,000
Butanes Used in Gasolines[b]	40,000,000
Net Butanes Available from Refinery Operations	8,000,000
Total Butanes Available from Natural Gasoline If All Were Recovered	47,000,000
Maximum Amount of Butanes Available from Current Gasoline Manufacture[b]	55,000,000
Maximum Amount of Butanes Available from Current-Scale Gasoline-Manufacture[c]	46,500,000[d]

[a] Bureau of Mines Report, 1932; other values are private estimates.
[b] Average Reid vapor pressure, 10 lb. per sq. in.
[c] If based on an average Reid vapor pressure of 12 lb. per sq. in. and including butanes from natural gas.
[d] Approximate.

Discussion

Specific Use of Butane As a Motor Fuel Cited

—L. V. Newton
Automotive Engineer, Byllesby Engineering and Management Corp.

THE use of butane as a motor fuel is relatively new, as it was only some time in 1930 that the Los Angeles Railway Co. fitted one of its double-deck buses to use butane. So far as I can find, this was the first successful use of this fuel in this country. Since that time, butane has been used successfully by a large number of truck operators on the Pacific Coast, especially in Los Angeles.

Observations made by these operators indicate that, with an engine having low compression, the power derived with butane as fuel was approximately the same as that derived with commercial grades of untreated gasoline. If, however, the compression were raised to about 6.5:1, the power output with butane was increased from 15 to 25 per cent. In regard to fuel economy, butane, as already indicated, develops the maximum power only when used in high-compression engines.

On part-throttle openings, butane is not working to best advantage. On the other hand, engines using gasoline as a fuel operate best on part-throttle openings because of the high manifold-vacuum, which aids vaporization. On full-throttle openings, butane shows up at its best. If this observation is concurred in, then it must be agreed that the use of butane is limited very largely to trucks and buses operated over long runs, with much of the distance covered while operating with full throttle. It is my belief that the use of butane will be confined largely to heavy-duty trucks in severe service, where it has been demonstrated that the economy is marked.

At present, butane is selling in the Los Angeles area for 4.5 cents per gal. as compared with gasoline at 12 to 14 cents per gal. Under these conditions, the economy of butane is high. The cost of conversion, that is, fuel supply-tank, heat exchange and mixing valve for the average heavy-duty truck, is approximately $175 to $200. Under existing costs of butane, the initial cost of conversion is quickly paid for.

As the demand for butane increases, the price undoubtedly will more nearly approximate that of gasoline. If, however, butane applications are confined to heavy-duty-truck service, there will still be economy in the use of butane even assuming that fuel cost is the same as for gasoline.

The other chief advantages in the use of butane are that:

(1) Engine oil is not diluted; hence, with proper oil-filter equipment, its life is greatly extended

(2) A lighter oil may be employed, which results in better lubrication of all engine parts

(3) Valves show less pitting and burning with butane than with gasoline

(4) Carbon deposit is much reduced

It appears that, where engines are equipped with a good air cleaner and an oil filter, the periods between overhaul will be extended when butane is used as compared with gasoline.

At present, butane cannot be as readily obtained as gasoline. On account of the relatively few vehicles that I believe will be converted to the use of butane, the distribution of the fuel undoubtedly will be limited. In Los Angeles, a dispensing pump has been installed by one of the filling stations for handling butane, and possibly other installations will follow.

After observing the experience of Pacific Coast operators with butane fuel I can only conclude that, in heavy-duty trucks, its use has distinct advantages and economy; and that, as distribution of the fuel is provided, its usage will increase.

Necessary Diesel Characteristics

THE Diesel engine's chief claim to consideration for tractor service lies in its recognized ability to produce power economically. This economy is obtained from two sources. First, because of its high compression the Diesel consumes less fuel per unit of power produced than do so-called semi-Diesel engines or other types of unconventional oil engines. In the second place the Diesel operates most satisfactorily on a wide range of cheap petroleum fuels. Though it does offer certain other advantages, the fact remains that reduction of the fuel bill is the Diesel's prime reason for existence in modern tractors.

No Diesel tractor business in reasonable volume may be expected unless the engine will render service as generally satisfactory as the gasoline engine. In European and certain other foreign markets operators apparently are willing to render extra care and attention to Diesel engines less reliable than gasoline engines in order that they may realize the economy such power affords. However, American operators will not tolerate any unusual maintenance or operating difficulties.

Some of the characteristics considered to be essential in the design of a Diesel engine suited to the service demanded of track type tractors may be set forth here, as follows:

1. Positive starting must be guaranteed.
2. The engine must idle smoothly on all cylinders and have the ability to follow rapid changes of load and speed over a reasonable range without missing, smoking or otherwise operating unsatisfactorily.
3. There must be no excessive pounding or roughness as is sometimes noted in certain designs where the rate of combustion is not properly controlled.
4. There must be no necessity for more frequent and more expensive maintennce operations than would be experienced with a gasoline engine of similar type and power.
5. All service and maintenance work must be simple enough to be performed by the ordinary tractor operator.
6. The design must insure complete exclusion of all dust, dirt, mud and water. Special emphasis is attached to use of suitable filters for the air and fuel supply systems.
7. The engine must be able to maintain rated output for long periods of time without any service adjustments for the purpose of eliminating smoking, pounding, roughness or other manifestations of unsatisfactory combustion.
8. It is essential that the engine operate successfully on a wide variety of those Diesel fuels commonly available. Any necessity for specifying costly fuels tends to defeat the purpose for which such an engine is designed.

—Excerpt from paper entitled "Some Diesel Tractor Problems" read by H. H. Howard at the National Tractor and Industrial Power Equipment meeting, Milwaukee, April 18-19, 1934.

Practical Production Experience with Surface Broaching

By E. S. Chapman
President, Amplex Mfg. Co.

ACTUAL production experiences with several types of surface-broaching machines are cited by Mr. Chapman, who states that the shape of the piece, the number and the location of the surfaces to be machined and the required hourly production all affect the selection of the most suitable type of equipment.

The parts chosen by Mr. Chapman for citation are: A steel yoke, a front-wheel control-arm, a steering knuckle, a steering-gear cross-shaft, a free-wheeling cam, a small malleable cast housing and another small part that presented an unusual problem.

In each case cited, Mr. Chapman considers the part under the headings: Material, description, condition, operation, limits and stock removed. Regarding the production equipment, the headings are: Machine, fixture, broach, operation, production, and broach cost.

SURFACE broaching has been discussed on previous occasions in various Sections of the Society, and sufficient understanding of its theory and its engineering aspects is now general. I therefore thought it would be more interesting to consider some actual production experiences we have been through in the last few months with a considerable number of installations of surface-broaching equipment which include the simple single-stroke type of machine, the duplex type based on two broaches working alternately in the same machine, machines carrying two or more broaches, all of which act together on each stroke, and continuous rotary machines where no time is lost in handling the work. The shape of the piece, the number and the location of the surfaces to be machined, and the required hourly production all affect the selection of the most suitable type of equipment.

The first piece to be considered is a steel yoke, shown in Fig. 1, of which the required production is very high:

[This paper was presented at the Production Meeting of the Society, Detroit, Oct. 11, 1934.]

Material.—Heat-treated forging
Analysis, S.A.E. No. 3135
Heat treatment, 1550 deg. fahr.
Oil quench
Draw to 3.8-4.0 Brinell
Forging weight, 2½ lb.

Description.—Stem approximately 3 in. long and 1 in. in diameter and two fork or yoke arms approximately 2 in. long, which end in flat bosses or knobs. The stem is turned and ground and the flat bosses are broached and drilled through.

Condition.—Forgings are made with the die split in the center. This allows some mismatching and shifting of forgings and also some flash completely around the yoke on the center line.

Operation.—The broaching operating locates and smooths the stock of the four faces on the flat bosses in relation to the turned and ground stem. Also, a stop lug is finished which must be in relation to the turned shoulder. It can be seen that finishing four such faces allows a chance for one or more faces to have excessive stock, while all four faces have the die draft and flash.

Limits.—Thickness of bosses, 0.743/0.757 in. or ±0.007 in.

Stock Removed.—From 3/32 to ⅛ in. of stock is broached off of each of the four faces 1⅜ in. in diameter.

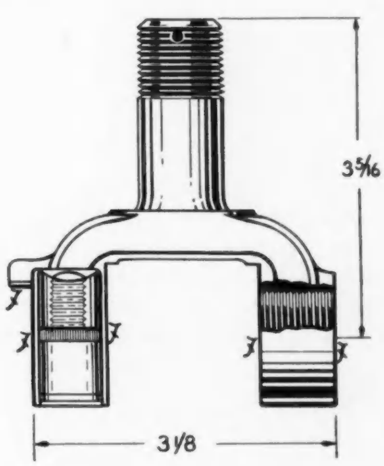


Fig. 1—A Steel Yoke

Equipment

Machine.—Continuous rotary broaching machine, gear driven. Two machines are on the job, each requiring approximately a 7-ft.-square floor-space. They are equipped with a rotary table approximately 4 ft. in diameter, rotating at 42 revolutions per hr. The table carries eight work-holding fixtures. The broaches are fastened into holders at four fixed positions around the table. The fourth and last position is merely a shaving operation to smooth the faces.

Fixture.—The part comes to the broach with the stem and shoulder turned and ground. The part is located in a hardened bushing against the shoulder, thus assuring uniform depth of stop lug. The part is hand clamped back against two narrow drivers, one driver behind each boss.

Broach.—Broach details are as follows:

Stations 1, 2 and 3; four broaches each, or 12 in all.

Station 4, shaving; three broaches, making a total of 15 details per set.

These broach details are made of H. S. steel. The teeth are radially cut and the rough milling of the teeth is allowed to extend back of the cutting portion so as to allow the flow of coolant to wash through the teeth and remove chips. Details are approximately 1 in. thick when new, and 8 in. long and 5 in. wide. They are set up, after sharpening, in interchangeable holders so that a No. 2 position, for example, can be changed on the job without resetting either of the other positions. The first 12 teeth taper 0.006 in. per tooth on the first or roughing position only. The balance of Station 1 and all of Stations 2 and 3 have a uniform tooth taper of 0.0021 in. per tooth. The shaving position has 22 teeth, the first 9 tapering uniformly at 0.0005 in. per tooth and the balance being straight. The broach speed is 8 ft. per min.

Operation.—Broach holders and broaches are stationary. The coolant is pumped through holes in the broach holders directly into the broaches. Pieces are unloaded and loaded while the table is in motion, thus allowing continuous operation. The production is 300 parts per hr. per machine.

Broach Cost.—At the end of the period covered by this study, the broach cost per piece was averaging \$0.0036. A good production milling-machine set-up was also in use during a large portion of this period and, for purposes of comparison, the milling cutter cost per piece was \$0.0128. This broach cost is a very marked decrease from our experience during the first few weeks of the job, as this was the first installation of its kind and a great deal had to be learned from experience about the proper steps between the broach teeth, the disposal of chips and coolant, and the details of the holding fixtures to resist the very heavy and varying pressures of the cut. The broach life in this instance varies from 0.0625 in. to 0.125 in. for the different positions, and an average of about 5000 pieces per grind is accomplished.

Two broaching operations are performed on the wishbone-shaped forging that we call the front-wheel control-arm, shown in Fig. 2.

Material.—Heat-treated forging
Analysis, S.A.E. No. 3135
Heat treatment, 1550 deg. fahr
Oil quench
Draw to 3.8-4.00 Brinell
Forging weight, 14 lb.

Description.—A wishbone-shaped forging having legs approximately 20 in. long. One boss is in the center of the piece and one boss at the end of each leg.

Condition.—Forgings are made with the die split in the center. This allows some mismatching and shifting of forgings and also flash completely around the center line.

First Broaching Operation.—After drilling four holes in an inside flange, a steel stamping is cold riveted into place. This serves to keep the part in alignment and adds to the rigidity. The first machining operation after this assembly is to broach the four sides of the leg bosses. While broaching the boss sides, a flat slot is broached in the end of each boss for locating purposes. Considerable variation in the amount of stock is encountered.

Limits.—Thickness of bosses, 1.368/1.382 in. or ±0.007 in. Width between bosses inside, 12.618/12.642 or ±0.012 in.

Stock Removal.—From 3/32 to ⅛ in. of stock is broached off of each of the four faces, each 1¾ in. in diameter.

Equipment

Machine.—There are three machines on this first broaching operation; one vertical mechanically operated broaching machine and two 25-ton vertical hydraulic broaching machines. These are single-row machines, broaching two bosses on one part at a time.

Fixture and Operation.—The part sits in a fixture, locating on the bosses for length. An equalizer clamps on the center

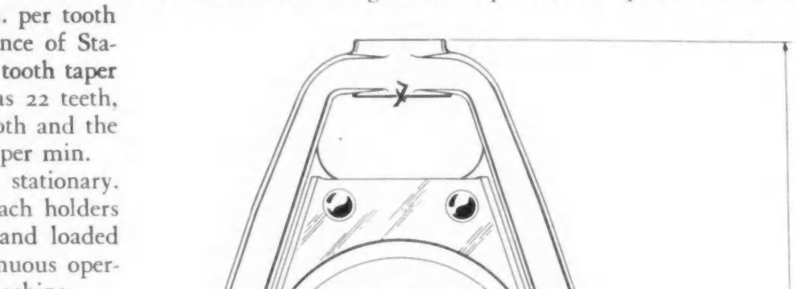


Fig. 2—A Front-Wheel Control-Arm

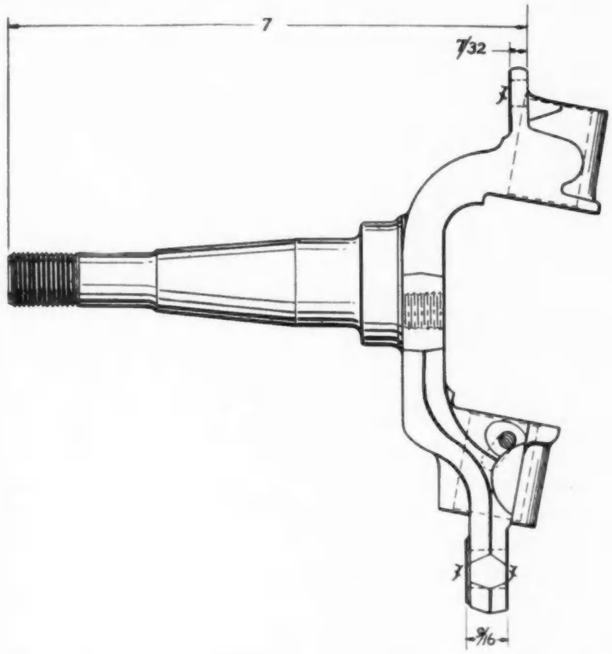


Fig. 3—A Steering Knuckle

boss and air clamps down on the end bosses. The fixture tilts for loading and unloading and allowing the broach slide to return.

Broach.—Broach details are: 2 in. wide, 1⅛ in. thick and 36 in. long, and made of H. S. steel. The broach speed is 44 ft. per min.

Production.—Parts per hour, 111 per machine.

Broach Cost.—The broach cost per piece on this operation at the end of the period averaged $0.0023. The broach life was about 0.250 in. and about 0.010 in. per grind is removed, with 5000 pieces produced between grindings. No fair comparison with milling-cutter costs can be given on this job, as the only milling set-ups in use were elementary and would not serve as a production comparison.

Second Broaching Operation.—One of the last operations on this part is the broaching of the inside face of the center boss.

Limits.—Thickness 1.109/1.123 in. or ±0.007 in.

Stock Removal.—From 3/32 to ⅛ in. of stock is removed from the back of the 1 13/16-in.-diameter boss.

Equipment

Machines.—There are two 25-ton vertical hydraulic broaching machines on this job. These are single-ram machines, broaching one part at a time.

Fixture.—The part sits horizontally in the fixture, with the outside of the leg bosses against the side stops and with cone plugs inserted in the boss holes from the inside to locate for length.

Broach.—One broach detail is required per machine. It is 46 in. long, 2 1/6 in. wide, approximately 1¼ in. thick, and made of H. S. steel. The broach speed is 44 ft. per min.

Operation.—Parts per hour, 111 per machine.

Broach Cost.—The average broach cost per piece on this operation is $0.0023. The broach life is 0.0625 in. Fewer broaches are required per set-up than in the first operation, but the shorter total life accounts for a nearly equal broach cost per piece. This operation is a good example of the possibility of broaching surfaces almost impossible to mill on a production basis as there is insufficient room for a milling cutter or arbor and about the only alternative would be a back spot-face operation, which would be unsatisfactory.

Our next part is the more familiar steering knuckle shown in Fig. 3.

Material.—Heat-treated forging
Analysis, S.A.E. No. 3135
Heat treatment, 1550 deg. fahr.
Oil quench
Draw to 3.8-4.0 Brinell
Forging weight, 6½ lb.

Description.—Conventional type of knuckle forging.

Condition.—Smooth surface on the forging, free from scale and flash and fairly uniform as to stock thickness.

Operation.—Broaching both sides of two 1-in.-diameter bosses and one side of a flange 1 in. wide and 2½ in. long.

Limits.—Thickness of bosses, 0.555/0.569 in. or ±0.007 in. Location from the bearing shoulder, ±1/64 in.

Stock Removed.—Removal of 3/32 in. on a side on two 1-in.-diameter bosses and ⅛ in. to 3/16 in. on the flange side.

Equipment

Machines.—Two vertical hydraulic double-ram machines, one cutting alternately, the other simultaneously.

Fixture.—Machine No. 1 fixtures are stationary; so, both fixtures are loaded and both knuckles are broached at the same time. The broach slide has to return to its upper position before the pieces are removed. Machine No. 2 is equipped with double broaches and a double ram. The fixtures swing horizontally so that the idle fixture can be unloaded and loaded while the ram is traveling upward.

Broaches.—The length is approximately 40 in.; the width, 1½ in.; and the depth, 1⅛ in. These broaches are made up of details approximately 10 in. long. The broach speed is 33 ft. per min.

Production.—Machine No. 1, 158 per hr.; Machine No. 2, 240 per hr.

Broach Cost.—The broach cost per piece in this instance is $0.00218. A total broach life of 0.180 in. is available, with 0.010 in. taken off per grind and about 7000 pieces machined between grindings. We have a good opportunity here for direct comparison of milling and broaching as, due to the quantities required, the best of milling equipment has been in use for some time and, over a similar period the milling-cutter cost per piece was $0.0203, or about nine times as great as the broach cost.

Our steering-gear cross-shaft, shown in Fig. 4, furnishes the next example and has the following specifications:

Material.—Heat-treated forging
Analysis, S.A.E. No. 4130
Heat treatment, 1550 deg. fahr.
Water quench
Draw to 3.7-4.00 Brinell
Forging weight, 3 lb.

Description.—An upset forging having a knob on one end approximately 2 in. in diameter. This knob is slotted or indented in the forging operation.

Condition.—Due to the location of this slot in the forging, the cold-trimming is a difficult operation; therefore, the stock to be removed by broaching varies considerably.

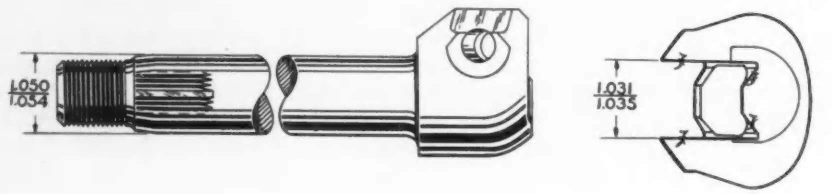


Fig. 4—A Steering-Gear Cross-Shaft

Operation.—This slot must be broached smooth on the sides and a V-shaped clearance broached at the bottom of the slot.

Limits.—The slot must be parallel and within 0.002 in. for width, 1.031/1.033 in.

Stock Removal.—Approximately 3/64 in. is broached from each side: 1⅜ in. long and 1 in. wide.

Equipment

Machine.—One duplex vertical broach (mechanical) with two rams.

Fixture.—Tilting type. The part locates in a bushing against a turned-and-ground shoulder and is located sideways by equalizing jaws on the sides of the upset head to divide the stock properly.

Broach.—Four broaches are used per set-up, each approximately 8 in. long, making one broach 42 in. long. They are made of H. S. steel and ground all over. The broach speed is 27 ft. per min.

Production.—125 parts per hr.

Broach Cost.—This type of broach has only 0.001 in. of grinding stock on the width, but can be sharpened by grinding approximately 0.005 in. from the face. The available total broach life is 0.050 in. on the face and about 10,000 pieces are finished per grind. The average broach cost per piece in this case is $0.00125. This is a good broaching job, difficult to handle satisfactorily in any other manner, and we have had cases of broaches running over 140 hr., or about 20,000 pieces, without removal for grinding. In this case, as in all others mentioned here, it is anticipated that the broach cost per piece will decrease with experience and improving practice.

The next example is a free-wheeling cam, shown in Fig. 5, somewhat different in that the piece is machined before broaching; so, there is no surface scale to contend with and two operations are performed in one setting by means of an indexing fixture. The characteristics are as follows:

Material.—Nickel-Molybdenum, Carbon .19-23
Forged and annealed to 4.1 maximum Brinell hardness
Forging weight, 2 lb.

Operation.—To broach one slot across the face of the part in relation to the sides of the cam. Then index 90 deg. and broach another slot at right angles to the first one.

Limits.—The width of the slot is 0.621/0.629 in. The depth of the slot is 0.125-0.135 in.

Stock Removed.—Approximately ⅝ in. wide and ⅛ in. deep from two sides of a ⅜-in.-wide ring.

Equipment

Machine.—One duplex vertical broach (mechanical).

Fixture and Operation.—The piece is located in the fixture on a splined stub arbor. An air clamp pulls the work into place. The broach is up. The fixture rocks in. The broach moves down. The fixture rocks out. The fixture is unloaded and loaded.

Broach.—Each broach is made up of three details, each ⅝ in. wide, 1¼ in. thick and 10 in. long, making a broach length of 30 in. The broach speed is 38 ft. per min.

Production.—127 parts per hr.

Broach Cost.—The broaches in this case have a total life of 0.125 in., but 0.005 in. is removed per grind, making a life of 25 grinds with about 8000 pieces produced between grinds. The average broach cost per piece is very low, being $0.00057.

Our next example is a small malleable cast housing, shown in Fig. 6, weighing about 1.8 lb. and having a flange on the bottom face.

Description.—The outside dimensions are 2¾ x 4 in. with an opening 1⅜ x 2½ in. giving 7 sq. in. of surface to be finished.

Condition.—Some pieces have a fairly hard, rough, chilled surface.

Operation.—The broaching operation locates and smooths the bottom of the flange with relation to the previously machined sides.

Limits.—The surface must be smooth and square and free from scratches.

Stock Removed.—From 1/16 x 3/32 in.

Equipment

Machine.—One 8-ton vertical hydraulic broaching press.

Fixture.—The fixture slides in and out to the broaching position. The part locates in a box-type fixture resting on a machined surface and held by a hand-operated cam-clamp. The cycle is to load the fixture with the broach up, and slide the fixture forward into place. The broach moves down. Then to slide the fixture back. The broach moves up while unloading and loading.

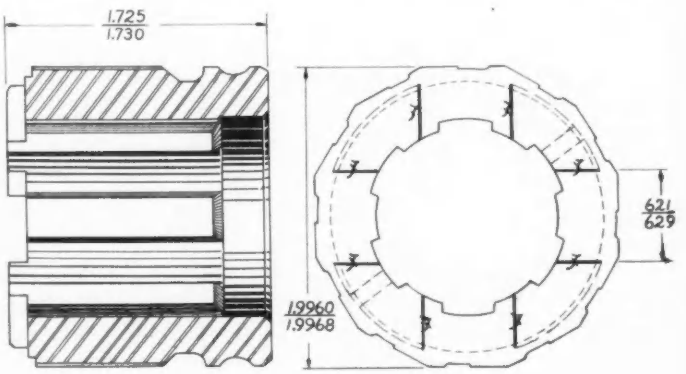


Fig. 5—A Free-Wheeling Cam

Broach.—The broach is approximately 4½ in. wide and 30 in. long and is in one piece made of H. S. steel. The broach speed is 18 ft. per min.

Production.—166 parts per hr.

Broach Cost.—These broaches have an available life of 0.050 in. and about 0.003 in. is removed per grind, making 16 grinds the life of the broach. Due to the wide surface being machined and the broach possibly somewhat shorter than it should be, the number of pieces between grinds is not as great as in many of our steel parts, 2500 per grind being the average, which gives an average broach cost per piece of $0.0018.

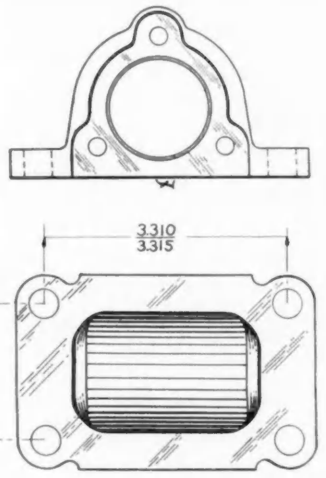


Fig. 6—A Small Malleable Cast Housing

The next and final example for discussion, shown in Fig. 7, presented an unusual problem. Four flat surfaces, two at each end, have to be held closely parallel and in plane with each other and closely parallel to the pitch-line plane of the threaded center-section. This part is made from bar stock of S.A.E. No. 1335 analysis, the blank weighing about 1 lb. A very high production rate is required. There is no heat-treatment before broaching. The part is clamped between cam-operated jaws having threaded inserts that bear on the pitch diameter of the thread. Provision must also be made for accurate longitudinal location of the parts in the fixtures. This involves some skill and experience on the part of the operator before the maximum output can be reached. The piece is threaded at the center portion for approximately 1½ in. with 1 3/16 in. at each end turned to 13/16 in. diameter.

Limits.—Thickness of the flats, 0.430/0.444 in. or ± 0.007 in. The flats must be in same plane within 0.005 in. and parallel with the threads within 0.001 in. per in.

Stock Removal.—Over 3/16 in. of stock is removed on each side at the maximum diameter.

Equipment

Machine.—Two vertical double broaching machines, mechanically operated.

Fixture and Operation.—The machine slide has two broaches; so, two pieces are broached at a time. The fixture is stationary; so, after the slide goes down, it is stopped until the work is removed. The cycle is that the broach is up and the fixture is loaded by screwing the part in the lower half of the split locater, up to a fixed stop. Then to clamp each pin separately by the hand-operated cam-clamp. The broach cuts down, the fixture is unloaded and the broach moves up.

Broach.—The broach details are: 14 in. long, approximately 1½ in. wide and 1 in. thick; it is made of H. S. steel. Eight details are required for setting up the complete machine on both sides. The broach speed is 30 ft. per min.

Production.—179 parts per hr. per machine.

Broach Cost.—The available broach life is 0.080 in., about 0.005 in. being removed per grind, giving a total of 16 grinds. In spite of the amount of stock, about 9000 pieces are finished between grinds and the average broach cost at present is $0.0019 per piece.

These experiences are based on the production of sets of parts for several hundred thousand cars, and we feel that these are rather dependable data for considering equipment of this nature. The broach as a cutting tool has the inherent advantage that the leading teeth are always roughers and the trailing teeth are always finishers. With a milling cutter, in contrast, the blades are first in contact with the rough and sometimes uneven surface and later are expected to produce a reasonably good finish. Except for the first tooth in a broach, the amount of stock removed by each tooth is always the same, provided the grinding is uniform. Another characteristic that favors the broach is the fact that a very heavy and substantial broach holder and slide, made of cheap materials, furnish the stiffness required for smooth action, and the amount of expensive high-speed steel is considerably less in proportion to the amount of metal removed per hour.

While we have experienced the usual troubles incident to getting new set-ups into full production, the average broaching machine is a much simpler, more rugged and trouble-free mechanism than the average milling machine and, in general, is less costly in original investment, in maintenance of machine, cutting tools, in floor space and manpower.

One of the inherent advantages of broaching is that separate roughing and finishing operations so common in milling practice are not required, which in itself saves half the total machine cost for the surface under consideration.

In conclusion, our experience indicates that, in specifying surface-broaching equipment, we should be sure of ample tonnage or capacity in the machine, and we have found some tendency on the part of the machine-tool builders to underrate the capacity required for a given job, possibly in their effort to keep the required investment as low as possible. This is false economy. The pressures involved vary greatly with the type of work, length of broach and other considerations; but absolutely rigid fixtures, free from spring and chatter and with very positive means of holding the part against the pressure of the cut, are of vital importance.

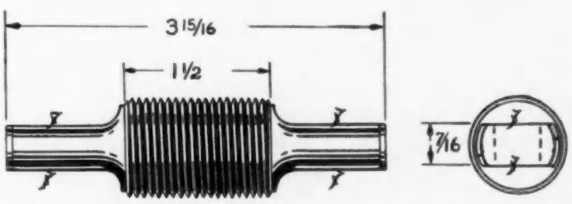


Fig. 7—A Small Part That Presented an Unusual Production Problem

Design-and-Application Trends in Railroad Motor-Trains

By Charles O. Guernsey[1]
Chief Engineer, The J. G. Brill Co.

THE history of the development of railcars or motor trains is reviewed and their economic application discussed. In Mr. Guernsey's opinion, the eventual design for general application will be some reasonable compromise between the past conservative and the present extreme designs. His conclusions are that:

Rail motor-trains properly applied can be largely used to hold and regain traffic for the railroads.

The principal competitor is the private automobile.

Motor trains probably cannot compete with the private automobile or the common-carrier bus, in frequent-stop local service.

The cost of operating service per passenger seat should be much less than that of present equipment.

Motor trains should be applied for operation over distances and at speeds where the overall time from point of origin to point of destination of the passenger will be less than by competing carriers, whether private or public.

Frequency of service must be considered, as well as schedule speed.

Because of speed, comfort and the like, such service should appeal to the public.

Streamlined motor-trains have been carried to such a point in streamlining and structural materials that the cost is excessive. There would seem to be a need for compromise construction.

The motor car more or less of past conventional types will continue to be used where the train consist must be varied.

The power equipment will be either carburetor or Diesel type, depending upon the conditions of application.

TO supply the background necessary for an intelligent discussion on the present status of railcars or motor trains, it is necessary to review briefly the history of the development of such equipment and the economics of its application. Equipment of this character has passed through three cycles and is entering a fourth.

The first cycle consisted of early groping attempts by various inventors to produce equipment of this type that would be satisfactory, but none of these early attempts survived. The second cycle, which lasted from 1905 to 1914, saw the production in some quantities of three types of cars. The third, which started in 1921 and lasted through 1929, saw a very general application of railcars, both as individual units and as power units for handling standard equipment as trailers. The fourth cycle, into which we are now entering, contemplates, in addition to service such as that of the third cycle, the use of specially designed self-contained complete motor-trains, designed to operate as a unit and not intended to operate with cars of existing types.

Historically, the railcar is about as old as the automobile industry. The first car concerning which any details are available was invented by Henry K. Shanck, was built for the Springfield, Ohio, street railway in 1887 and was exhibited at the Ohio State Fair that year. It was equipped with two Foos gas engines. It is said that Charles E. Duryea got the inspiration for building his first automobile from an examination of this car. The first company to attempt commercial production was the Patton Motor Car Co., which lasted from 1897 to 1900. A mechanical drive eight-wheel car was built by Jewett in 1899. The Strang gas-electric design was built to the order of the Strang Gas-Electric Co. by

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[1] The author wishes to acknowledge his indebtedness to L. K. Sillcox of the New York Air Brake Co., Col. E. J. W. Ragsdale of the Budd Co., E. E. Adams of Pullman, Inc., and V. R. Willoughby of the American Car & Foundry Co., for their cooperation in furnishing certain data used in this paper.

The J. G. Brill Co., in 1907. Various other experimental units were built also. All of these cars may be considered as being in the first cycle, since they did not reach any particular production nor were they generally accepted.

Beginning about 1905, three commercial types were developed, one of them a mechanically driven gasoline-or-distillate-engined car known as the McKeen, some 200 of which were built. These cars ranged from 55 to 70 ft. in length and had direct reversible engines of 200 or 300 hp., mounted transversely of the car on the front truck, with the cylinders extending up into the body. They drove one axle of the forward truck through a two-speed transmission. Some of these cars are still in operation on the Union Pacific and other western railroads. The Hall-Scott Motor Car Co., Berkeley, Calif., built a number of successful mechanical drive cars, having a typical four or six-cylinder vertical engine, mounted in the front of the car body and driving through a sliding-gear transmission to one or both axles of the rear truck, as the conditions required. The third design was a gasoline-electric unit, designed by the General Electric Co., having an eight-cylinder V-type gasoline-engine developing 175 hp. and using a 600-volt direct-current electrical transmission consisting of a generator, a suitable controller and two traction motors mounted on the front truck. The car bodies and trucks for these cars were built to the order of the General Electric Co. by the Wason Manufacturing Co., a subsidiary of The J. G. Brill Co. Some 88 of these units were built and a number of them are still in service, many having performed between one million and two million miles of service.

When we consider the state of development which the internal-combustion engine had reached at that time and the lack of what would now be considered necessary materials, such as alloy steels, these various cars reflect considerable credit on their designers even though, in the light of present-day practice, many shortcomings could be found. The manufacture of these cars was discontinued at the beginning of the World War, thus ending the second cycle.

During the War, tremendous strides were made in the design of internal-combustion engines and their accessory apparatus, and in the various materials and manufacturing processes for their production. This opened up new possibilities in the railcar field. Coincidentally, the operating costs on railroads had risen materially, so that there was an urgent need for the greatest possible economy in railroad operation. So far as the railcar is concerned, this was particularly apparent in handling the lighter services on branch lines. This led to the development by various builders of a number of light-weight types.

During 1921, a light-weight car seating 40 passengers, having space for 1 ton of baggage and capable of top speeds of about 45 m.p.h., was developed. This car weighed about 30,000 lb. and was originally powered with a four-cylinder 70-hp. and later with a six-cylinder 90-hp. engine; it found wide application in branch-line service, both here and abroad, a total of about 140 having been built. The success of this car led to the development of a larger car having a length of 55 ft. and powered with a six-cylinder 6 x 7-in. engine developing about 190 hp., which was capable of handling a light trailer for service on branch lines. This car was geared for a top speed of about 60 m.p.h., although it is interesting to note, in view of current trends toward high power and streamlining, that it was able to make about 70 m.p.h. when hauling a trailer on level track, with a total of only 190 hp. The total weight of such a train, loaded, was about 110,000 lb. These cars likewise found general application, a total of 82 being built. This is the largest mechanically driven car to find general application during this period. The engine drove through a specially designed three-plate clutch, with a five-speed transmission mounted in the bolster of the front truck, thence both ways through suitable propeller shafts to bevel-gear axles. The reversing was arranged in the axles, so that all five speeds were available in either direction.

During this entire period, the success of one size called for the development of a larger, so that the next development was a 250-hp. gas-electric unit. Some 80 cars of this type were built. The engine was a 7¼ x 8-in. six-cylinder unit, operating at 1100 r.p.m. and rated at 250 hp. This was followed by a 300-hp. design, of which about 65 were built. This used a Hall-Scott 7½ x 9-in. six-cylinder engine, rated at 300 hp. at 1100 r.p.m.

A number of cars were built using two engines either of the 250 or 300-hp. type. This was followed by the development of two similar engines, 8¾ x 10½ in.; a six-cylinder type rating 415 hp. at 950 r.p.m. and an eight-cylinder type rating 550 hp. at 950 r.p.m. These larger engines were applied in cars 73 to 80 ft. in length and having a weight complete, including heating plant, varying from about 130,000 to 145,000 lb. All of these units from the 250-hp. size on up were built to handle one or more standard steel coaches, baggage cars, or the like, as trailing load. Another type had a typical 550-hp.-engine unit with three specially designed trailers weighing about 80,000 lb. each and each having a length of 73 ft. 6 in., one or more of which were handled by each of the motor cars on this order. This car was also expected to handle, as the occasion required, existing steam equipment; for example, a train having a total of eight cars. While this is more tonnage than is recommended for equipment of this character, it is by no means unusual. Some 18 or 20 cars of this general type were built shortly before the depression in 1929, and this type will be considered later in comparison with some of the newer developments as a means of indicating the economics of the various types of equipment for various sorts of service.

It will be noted that, during the period from 1921 through 1929, the railcar had been developed from a single unit to a power car capable of handling a train with anywhere from one to ten cars coupled, depending upon the nature of the service. It should be particularly emphasized that these cars were designed with sufficient strength, buffing and draft capacity to operate safely and satisfactorily in such trains with existing heavy equipment, and carried suitable couplers, draft gears, and the like, to that end. The examples cited are all from the development made by The J. G. Brill Co., but similar developments were being made at the same time by other manufacturers, notably the Electro-Motive Co., whose experiences more or less parallel the examples given.

During this period, the primary incentive in substantially all cases was minimum overall cost to the railroads so that, in general, these designs were made for minimum first cost consistent with the greatest possible reliability in service. The operating records of equipment in service on the majority of the major railroads of the United States offer complete proof that these objectives have been achieved. Most applications of cars of this type have been either on branch lines, secondary lines, or, if operated on the main line, were in frequent-stop local-service. They have, in practically all cases, been considered as a substitute, train for train, for the previous steam-train equipment.

The motor railcar, if properly applied, offers many advantages other than the saving in operating cost on which so

much emphasis was laid during this period; but, in general, the plea to offer improved service, either by reason of better schedules, improved frequency or better appointments, which to the manufacturer seemed to be attractive, fell largely on deaf ears. In the meantime, the improved highways of the country were being extended at a tremendous rate. This, together with the improvement in the vehicles themselves, led to the wider general use of the private automobile in intercity travel and brought the development of the motorbus as a cross-country common-carrier. The result of these developments is that short-distance riding on the steam roads, at least in territories where good highways are available, has largely disappeared. This does not apply to suburban service, nor to local service in densely populated areas, such as the Middle Atlantic Seaboard. Generally speaking, however, the short-haul frequent-stop passenger-business is probably permanently lost to the railroads. It seems reasonable that, under present conditions, short-distance travel of this character can be handled more economically on the highways. Parenthetically, it is of interest to note that the majority of intercity bus-rides are of the short-haul type, since the average length of ride on intercity bus-lines during the year 1932 was only 17 miles.

It does seem possible that other classes of riders can, to a large extent, be brought back to the railroads by the intelligent use of motor-train equipment. Recent experiments with fare structures, particularly in the southeastern territory, where passenger fares had been dropped to 1.5 cents per mile, have brought a very sharp up-turn in railroad transportation. This indicates that the public still prefers to travel by rail, where it can do so at a competitive fare. It should be noted that this improvement in riding was made solely by reason of fare change and was not caused by the substitution of new equipment, faster schedules or other conditions. Whether the railroads can handle passengers profitably at 1.5 cents per mile, depends upon many features, some of them beyond the scope of this paper. Certainly, however, motor-train equipment, within proper size-limits, can be operated at much less cost than steam trains. Depending upon the size of the train required, this operating cost may be somewhere between one-third and one-half the cost of a steam train of corresponding capacity.

While a great deal is said on both sides about competition

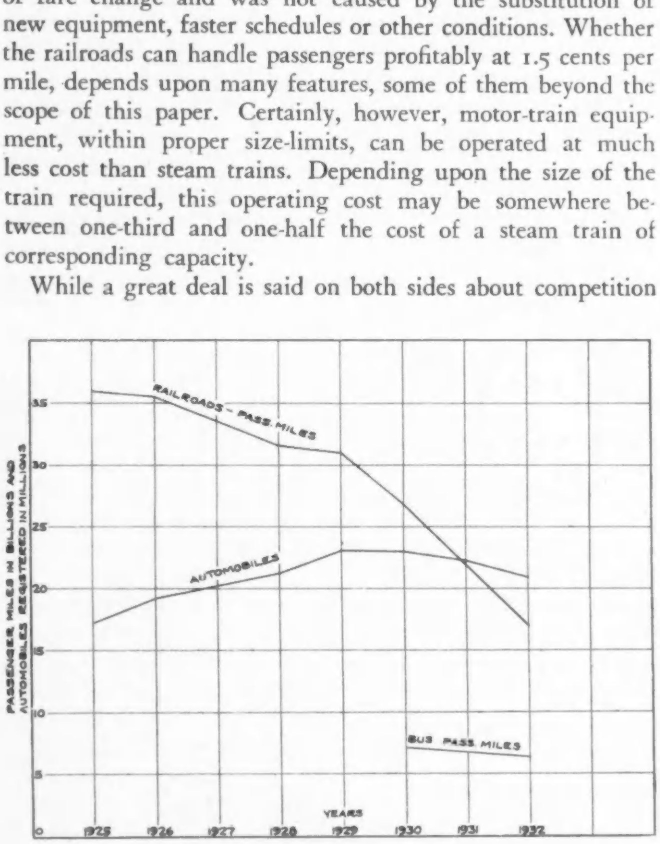

Fig. 1—Curves Illustrating Competition Between Steam Trains and Automotive Vehicles

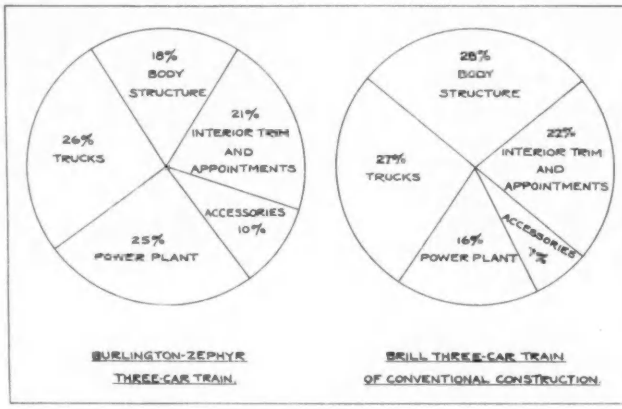

Fig. 2—Comparison of Weight Distribution Between Two Modern Railroad Trains

between the steam train and the motorbus, the fact is that the private automobile is the steam train's principal competitor on rides up to perhaps 300 miles in length, as indicated in Fig. 1. If, therefore, something can be done which will persuade us to leave our cars at home when taking journeys to nearby cities, the railroad traffic will improve to that extent.

The decision of whether to patronize the railroads or drive his own car is presumably made by the individual on the basis of convenience, speed, including frequency of service, safety and cost. While, obviously, the cost per mile for driving an automobile is greater than any normal railroad fare, we are all prone to count only the out-of-pocket cost. On such a basis, at the present standard rates of fare, and particularly if two or more persons are going to the same destination, the traveler could apparently justify the use of his own automobile. Insofar as the riders on intercity buses are concerned, apparently the low cost for fares is largely responsible for their choice of this vehicle.

Bearing the above facts in mind, it would seem to be possible to define a new sort of application for motor-train equipment. Motor trains could be operated at advantage to the railway and to the traveling public if (*a*) the length of the journey is such that the operating of a personal car becomes somewhat of a task; (*b*) the speed and frequency of service are such that the time from point of origin to ultimate destination will be no more than with the private automobile; (*c*) the equipment is comfortable, safe and generally attractive; (*d*) the cost of such service is at least no greater; and (*e*) if there is a sufficient potential volume of traffic to justify such service.

Probably the foregoing conditions can be met if (*a*) the distance is not too short, probably not less than 150 to 200 miles; (*b*) if the equipment is operated primarily as a through service, avoiding the delays incident to secondary stops, and thus permitting high schedule speed; (*c*) if the equipment is designed for reasonable first cost and operating cost; and (*d*) if the traffic congestion on the railway does not too seriously interfere with such operations. It would appear that, purely as a matter of illustration, the service between such points as Chicago and St. Louis, St. Louis and Kansas City, Chicago and Cincinnati via Indianapolis, Chicago and Detroit, might be typical operations where considerable traffic might be regained from both the private automobile and the highway common-carrier.

In considering the matter of speed, frequency of service must also be taken into account. From the standpoint of the

passenger, presumably the most desirable arrangement would be to dispatch relatively small individual cars at as frequent intervals as the traffic would justify. However, this is in most cases not practicable because of the higher operating cost per passenger seat and particularly because of the interference with other traffic on the lines. The major portion of the railroad revenue and profit is obtained from freight; therefore, any operation which interferes with the movement of the freight trains is to that extent undesirable. Consequently, the loss and inconvenience resulting from such interference must be balanced against the additional revenue to be gained from the passenger service. It seems probable that the compromise will be motor trains using a minimum of perhaps three cars, in preference to single-unit equipment.

For the services just under discussion, coach operation should be considered primarily. It would seem also that, while the equipment should be comfortable, it should not necessarily be luxurious. The recent three-car, articulated trains delivered by the Pullman Co. to the Union Pacific and by the E. G. Budd Mfg. Co. to the Chicago, Burlington & Quincy, are intended for such daylight services. Both of these trains have been fully described; so, it will suffice to say that each consists of three articulated cars—that is, having adjacent ends of intermediate cars mounted on the same truck—each driven by a 600-hp. engine, both streamlined and both built to the minimum possible weight consistent with safety. The weight in each case is about 200,000 lb.

The Union Pacific train is framed entirely of aluminum, making use of extruded sections, the entire shell of the body being considered as structural material and treated as a tube in calculating loads. The body structure of the Burlington train is fabricated from 18/8 stainless steel in light-gage sections, assembled by the Budd shot-weld process. The strength of the various members is obtained by using built-up struts, girders, columns and beams. Both trains are air conditioned, each is lighted by an indirect system and both carry oil-fired heating-equipment, a hot-air system in the case of the Union Pacific train and steam in the case of the Burlington.

Both trains are equipped with newly developed braking apparatus designed to give the minimum possible distance of stop consistent with freedom from wheel sliding, the rate of stop being in each case under the control of a decelerometer or retardation controller, arranged so as to regulate the braking pressure to maintain a uniform rate of retardation in miles per hour per second, as nearly as possible, throughout the stop from top speed to standstill. Such a device is required because of the varying coefficient of friction between the brake shoe and the wheel, which has a value perhaps as low as 0.08 at 90 m.p.h. and rises to 0.3 at static. The braking equipment will safely stop these trains from 90 m.p.h. in about the same distance as the normal steam train from its average speed of say 60 m.p.h. The braking equipment for the Union Pacific train was designed by the New York Air Brake Co., and that of the Burlington by the Westinghouse Air Brake Co.

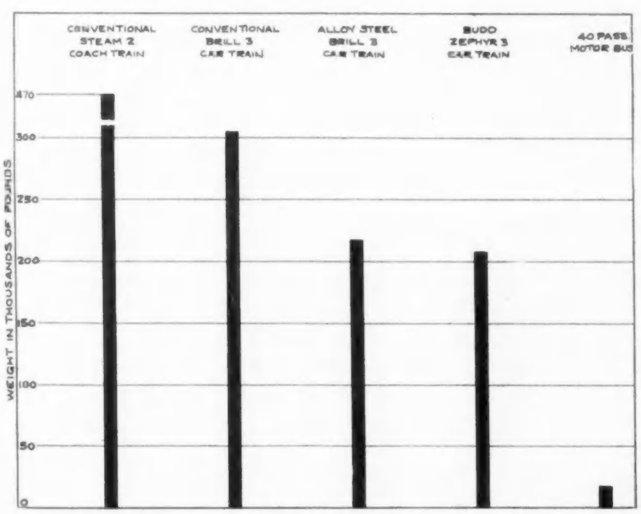

Fig. 3—Weight Comparisons Between Several Types of Railroad Trains and a Motorbus

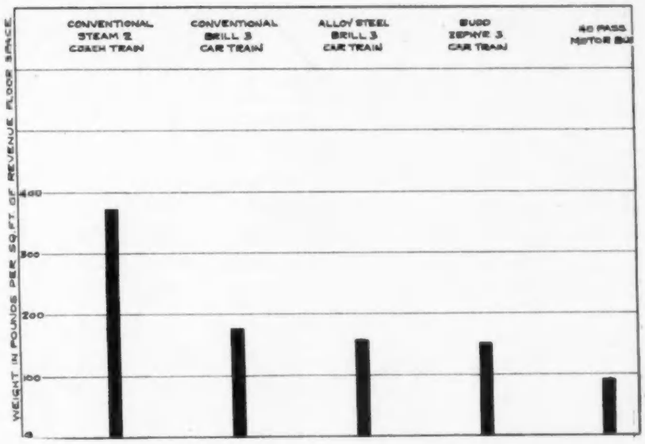

Fig. 4—Relative Weights per Square Foot of Revenue Space for the Various Units Specified in Fig. 3

Both of these trains have been streamlined very completely, not only as to front and rear ends, but also as to cross-section, including a complete sheathing of the under side of the car; likewise, sheathing or shrouding of the trucks. Many details, too numerous to mention, have been given special treatment to assure comfort for or even, in some cases, luxury for the passenger.

For service over longer distances, frequency of service is not so important. Therefore it would seem that, for such long-distance services, still larger trains will be dispatched at less frequent intervals. The Union Pacific Co. now has on order with the Pullman Co. one 900-hp. six-car train and two 1200-hp. nine-car trains, intended for long-distance operation. For such long-distance travel, sleeping-car facilities will be required in addition to coaches. These Union Pacific trains are so arranged; in other words, they will have more or less the same consist as a typical transcontinental train, but will be designed to take full advantage of the light weight, streamlining and internal-combustion-engine power typical of other motor trains. The design characteristics are similar, in general, to the smaller train.

Apparently the situation, so far as this newer type of application is concerned, can be summarized by saying that there is a minimum capacity of train and a minimum length of operation below which, for the reasons stated, it is not reasonable to go. It also appears that there are possibilities for larger, longer, higher-powered long-distance trains. Just how far the trend may be reasonably carried in that direction again will depend upon operating conditions; but, the larger the train is, with its attendant higher first cost and operating cost, the more nearly the motor train approaches the proper sphere of the steam locomotive.

It also should be borne in mind that light-weight streamlined modern steam-locomotives, designed for the application,

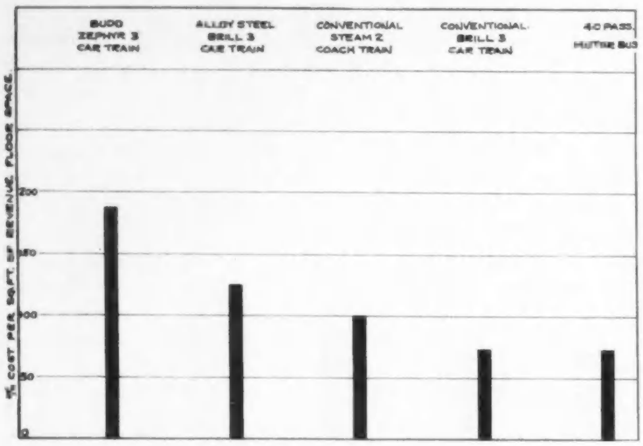

Fig. 5—Relative First Costs per Square Foot of Floor Space for the Various Units Specified in Fig. 3

can handle these larger trains to good advantage. We should not confuse the potential operating economy on light-weight steam-trains with the actual operating record of existing trains using heavy or obsolete power. It appears that while the direct operating cost of internal-combustion-engine power, even in comparatively large sizes, will be materially less than that of steam locomotives of comparable sizes, it is nevertheless true that the first cost of internal-combustion-engine equipment is far higher than the first cost of the steam equipment and, therefore, the overall cost may be in favor of one or the other depending upon conditions determined by each application.

In attempting to appraise these newer motor trains and to compare them with the motor railcars of previous types, certain important distinctions must be kept in mind. The previous railcars were required to operate with existing equipment, to couple and haul whatever might be hitched on, and were designed primarily with economy in first cost and operating cost in mind. These new articulated units have been designed to operate as an independent, specialized type of unit, not intended to handle other equipment. Furthermore, the emphasis, at least in the small trains built thus far, has shifted from first cost and is concentrated more on

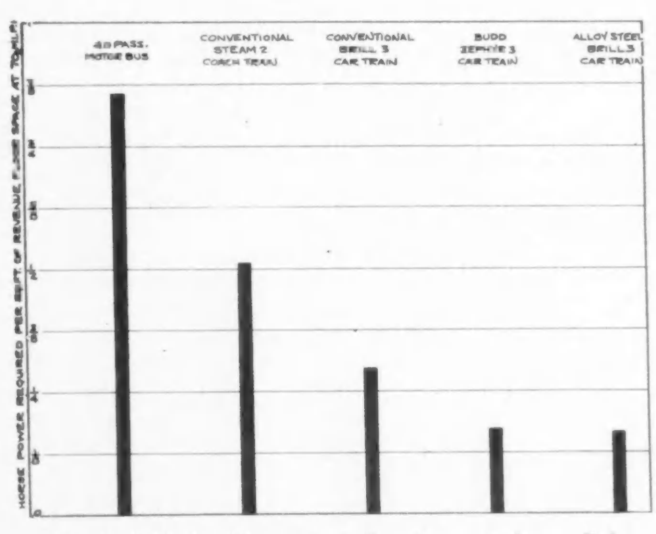

Fig. 6—Relative Horsepower Requirements for a Balancing Speed of 70 M.P.H. for the Various Units Specified in Fig. 3

speed, comfort and other features which are intended to attract and hold riders. Within reason, this change of attitude seems to be correct and well justified although, as recently as five years ago, the high first cost of the present equipment would not have been tolerated.

In the case of this class of equipment, as in most engineering matters, it is difficult to make a general statement which will apply to all cases. Nevertheless I offer the opinion that, for general application, the eventual design will be some reasonable compromise between the past conservative and the present extreme designs. Without in any way attempting to deprecate the value of light weight or the extremes to which streamlining has been carried, and with full appreciation of these two features of design, it nevertheless seems to be open to serious question whether some less radical compromise might not be more satisfactory, all things considered.

Closing up of all of the underframe equipment, as has been done in both of these cases, adds very materially to the first cost. It also adds to the difficulty of installing, inspecting and maintaining the necessary apparatus which must be installed in such space. In addition, the shrouding of the trucks makes them difficult of access for inspection and adds not only to the first cost but also to the maintenance cost. It should be appreciated that, while these trains have been advertised as capable of a top speed of 110 m.p.h., which has, in fact, been demonstrated by the Burlington train, it is nevertheless true that in regular service the prime objective is to raise the schedule speed rather than the top speed. Under certain proposed applications, a schedule speed of 60 m.p.h. is intended, which probably would require an average running speed of some 70 m.p.h. These extreme streamlined features no doubt have some value at this speed; but, with a given horsepower and a three-car train, the differential in the neighborhood of 70 m.p.h. would seem to be not more than 2 to 3 m.p.h. In my opinion, this can well be sacrificed in the interests of lower first cost, easier inspection, lower maintenance cost and greater accessibility of accessory apparatus.

In a similar manner, for the average application, the extreme in first cost incident to the use of expensive structural materials for the body seems hardly justified. It should be borne in mind that, in a conventional three-car motor train, the steel entering into the structure of the car body represents only some 28 per cent of the total train weight. Through the courtesy of Colonel Ragsdale of the E. G. Budd Co., the distribution of weights of the Burlington train has been made available. This indicates that 18 per cent of the total weight is in the body structure. Fig. 2 shows the distribution of weight as between two typical trains.

These trains are not directly comparable, since one of them is a conventional train of three cars on six trucks, using a gas-electric powerplant, as against a three-car articulated stainless-steel train mounted on four trucks and using a Diesel engine. It nevertheless seems to be true that it would be possible to build a train of the proportions of the three-car articulated trains under discussion, from ordinary structural steels, without adding more than some 10 or 12 per cent to the total train weight. The reason for this becomes obvious when the relatively great importance of the weight of the powerplant, accessories, trim and appointments, and trucks is taken into account. Calculations have been made indicating that, by the use of a low-grade alloy-steel for structural purposes, the total weight of a three-car articulated train, such as those under discussion, would not be increased more than about 10,000 lb. If such trains are to be applied in frequent-stop service—which we have shown to be improbable—

or, if they are to be operated on lines having extreme grades, probably the very maximum of weight saving, even at a material increase in first cost, is justified. If, on the other hand, the train is to operate on railroads having normal grades and stops only at infrequent intervals, there then appears to be a serious question whether the extreme addition to first cost of such special cars is justified. It seems rather peculiar that so much emphasis is concentrated on the weight of body structure when, at most, it only represents 28 per cent of the total train weight, using the typical examples cited.

We have often heard the weight of the steam train compared, presumably to its discredit, with the weight of airplanes, automobiles, motorbuses and now, the high-speed light-weight trains. It is true that the steam trains in the past have been heavy; possibly they have been too heavy. It should be borne in mind in this connection, however, that the primary thought, both on the part of the builder and the operator of railroad equipment, is safety. It also should be borne in mind that cars for steam-train operation must be designed with sufficient buffing, draft and end-construction capacity, to operate in long trains and avoid, so far as is humanly possible, fatal accidents in the case of derailment or other accident. American trains run far heavier per passenger or per foot of length than European trains. That this policy has been well justified is shown by the exceptional safety record which the American railroads have maintained. Even in case of serious accident, the number of injuries is remarkably small. Some recent experiences abroad indicate the disastrous consequences of neglect of this factor. It is true, of course, that the buffing or accident-resisting structure need be only in proportion to the total weight of the train; so, to an extent, weight begets weight and, conversely, the lighter-weight trains now under discussion can be operated with equal safety if the proper proportions are maintained.

Comparisons of weight are usually based on passenger capacity. Since, however, the number of passengers per square foot of floor space or per cubic foot of volume varies widely with the degree of comfort provided for the passenger, it appears more reasonable to make a comparison on the basis of weight per square foot. Fig. 3 shows the total weight of a conventional steam train, including a suitable locomotive, a conventional three-car motor-train, a three-car alloy-steel train of the articulated type, a three-car stainless-steel train, and a conventional 40-passenger motorbus. Fig. 4 shows the relative weights per square foot of revenue space for these various units, showing that the weight runs about 90 lb. per sq. ft. of revenue floor-space on a modern 40-passenger bus, about 150 lb. for the stainless-steel train, about 158 lb. for the low-grade alloy-steel train, about 175 lb. for the conventional three-car motor-train, and about 370 lb. for the steam train.

While on this subject of comparison, the relative costs of these various vehicles are of interest. Fig. 5 shows the relative first costs per square foot of floor space, showing that the motorbus and the conventional three-car motor-train are substantially the same, being about 73 per cent, taking the two-coach steam-train as 100 per cent; while the alloy-steel three-car train would represent about 125 per cent and the stainless-steel train about 178 per cent. These data are admittedly approximate, but we believe sufficiently accurate for the present purpose.

Fig. 6 also indicates the relative horsepower requirements for a balancing speed of 70 m.p.h., for the several units under discussion. Fig. 7 indicates the total horsepower requirements of each of these units, at various speeds.

Because of the better alignment possible and the improvement in streamlining and riding qualities achieved thereby, the newer trains have been of the articulated type. This introduces some problems in connection with any change of train consist, that is, the addition or elimination of cars; but this is probably not a serious objection where the train is running continually in a more or less fixed type of service. This complication is somewhat serious, however, from the standpoint of shop requirements, in that it means either an expensive break-up of the train during the shopping of the motor unit, or the tieing up of the complete train during such repairs.

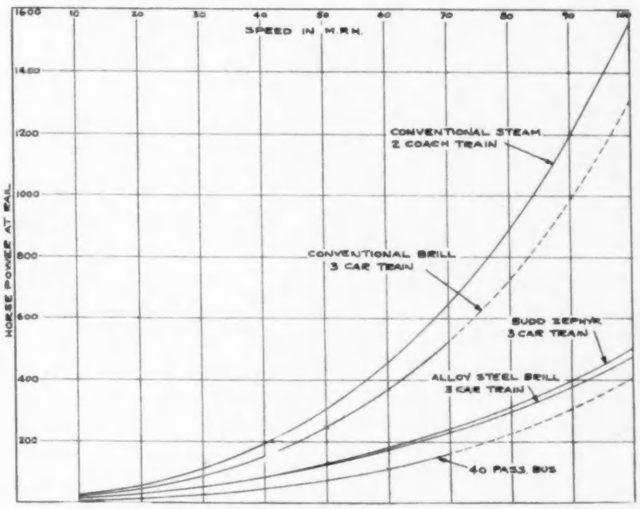

Fig. 7—Total Horsepower Requirements for Each of the Various Units Specified in Fig. 3

My opinion is that a distinction should be made between comfort and luxury. After all, the passengers who can afford luxury travel are largely patronizing the railroads at present. Those to be attracted are interested in low cost of transportation. If such a distinction were made, it is probable that a greater number of passengers could be accommodated with a given class of equipment, and that the first cost of the equipment could be reduced and the possible revenue increased.

There has been no railcar business worth mentioning in the United States since early 1930. I have shown that the trend has been constantly toward larger trains and higher power, and that the single-unit car, generally speaking, has more or less passed out of the picture, although some cars of this latter type have been built for export. Streamlined single-unit cars have been developed, but have aroused no interest on domestic railroads for the reasons set out earlier in this paper. It seems curious, in view of this situation, that a number of experimenters have spent a great deal of time and effort in developing single-unit cars. In most of these cases, extreme emphasis has been put on the very minimum of weight. My opinion is that extremely light-weight cars are not safe for high-speed operation, even if they were economically justified, regardless of the merit of the structural design employed. Such cars must have sufficient weight, particularly front-end weight, to cope safely with highway collisions, particularly with heavy trucks. Apparently nothing but brute weight and strength can cope with such a situation. It is also true that a comparatively high minimum weight is required to assure operation of signals, spring

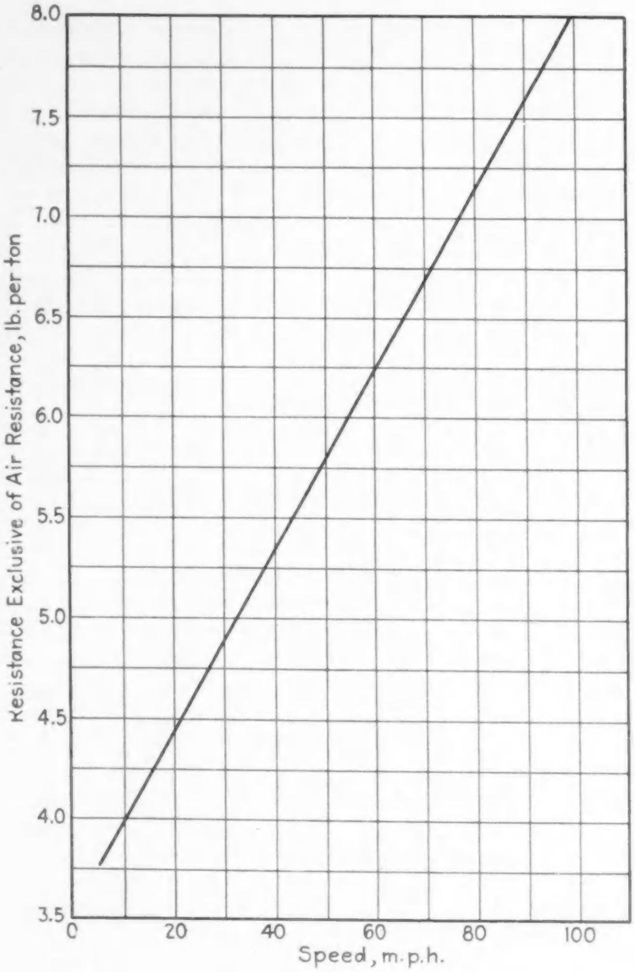

Fig. 8—Curve Showing Total Resistance in Pounds per Ton, Exclusive of Air Resistance

This curve is for a high-speed Diesel gas-electric three-car loaded-train. It is based on twelve axles, each carrying an average load of 13 tons

frogs, and the like. Some cars which have been built have such a low weight on the leading axles that they would not even cut through the ice in flange grooves, and, therefore, are subject to an extreme hazard of derailment in freezing weather. It is not at all uncommon, particularly at country crossings, to have the flange groove filled with gravel and sand, which likewise constitutes a hazard unless the weight of the train, particularly on the leading axles, is adequate. In view of all these facts, a conservative engineer cannot help but look askance at such efforts.

In comparing weights or weight per horsepower, it should be borne in mind that these trains have a rolling resistance, due to friction, varying from about 3.5 to 8 lb. per ton of weight—as shown in Fig. 8—whereas the highway vehicle will have a rolling resistance of perhaps 40 lb. per ton. Further, the highway vehicle is compelled to make frequent stops and to negotiate steep grades, whereas, on the railroads, the grades seldom exceed 1 per cent and, for the service outlined, the stops are very infrequent. This is a further indication of the comparative unimportance of weight for such services.

As an indication of the relative values of streamlining, Fig. 9 shows the variation in horsepower requirements for various values of the air-resistance coefficient *K*. This value is presumed to be 0.0024 for a conventional train of ordinary contour and having the usual recessed windows and doors and the usual protruding stepwells, journal boxes, grab iron, stirrup steps, and the like. For a three-car train, the coefficient *K* equals 0.0015 can apparently be achieved with a very moderate amount of streamlining so far as the ends are concerned, but with reasonable attention to smooth, sleek side and roof contour. Tests indicate that a coefficient of *K* equals 0.001 can be reached by proper streamlining of the ends and cross-section, but without going to the extreme of shrouding the trucks and underframe equipment.

It is felt that *K* equals 0.0008 represents the air resistance of a three-car fully streamlined train. A comparison of horsepower at the various speeds can readily be determined on the basis of these assumptions. Fig. 10 shows the expected performance of a 600-hp. three-car, articulated, fully streamlined train, at various altitudes and on various percentages of grades. Recent tests have indicated that this curve is substantially correct. Fig. 11 shows the total resistance of a three-car train having a frontal area of 117 sq. ft. in still air, assuming a coefficient of *K* equals 0.001.

The first streamlined design developed in America as a result of wind-tunnel tests is an electric car, and is of inter-

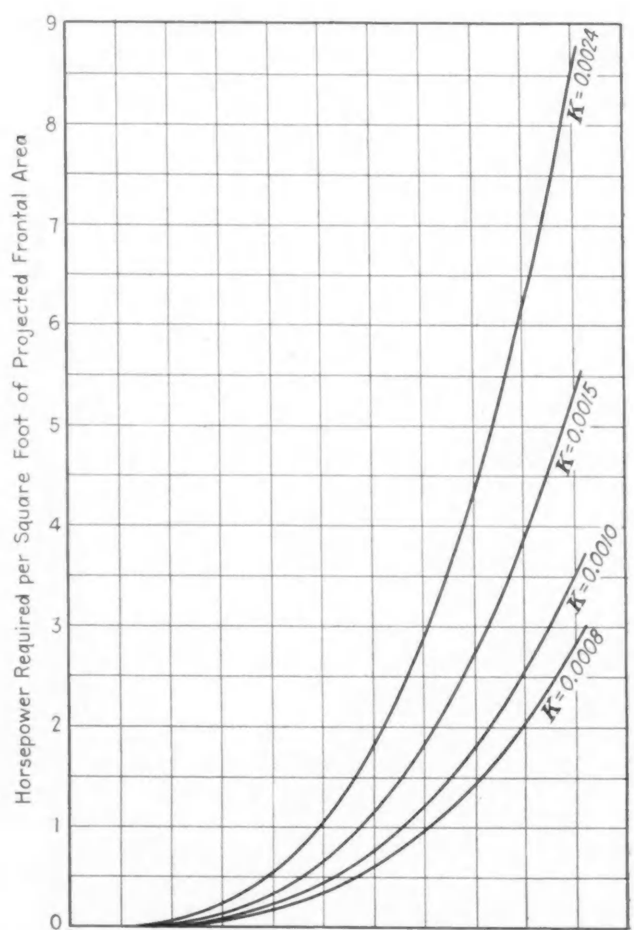

Fig. 9—Curves Showing Variation in Horsepower Requirements for Various Values of the Air-Resistance Coefficient, *K*

The curves are for a gas-electric high-speed streamlined-train, the overall efficiency being 75 per cent

est because it is demonstrating a saving of about 40 per cent in power at speeds of 70 to 80 m.p.h.

The fact that streamlined articulated trains have been developed to meet special needs by no means indicates that previous types will no longer be desired. There are many services in which the passenger-carrying capacity is a secondary consideration, the principal revenue being obtained from express, milk, parcel post and, sometimes, freight. Conventional types will continue to be used and to make an excellent showing in such applications.

In the matter of power equipment, the conditions have also been changing. Substantially all of the 1500 odd railcars in operation in the United States have carburetor-type engines, mostly operating on gasoline, although a few on certain western railroads, such as the Union Pacific, have been equipped for burning distillate. Considering the first cost of such engines as compared with corresponding Diesel engines and the annual mileage operated by the average car, this probably represents in most cases the most economical equipment. The situation is, however, being changed by reason of the excessive gasoline taxes charged in some areas.

Whether the Diesel engine is more economical than the gas engine can be determined by analyzing the operating conditions. The Diesel engine is higher in first cost, greater in weight, possibly higher in maintenance cost—although our Diesel friends may dispute this suggestion—and requires

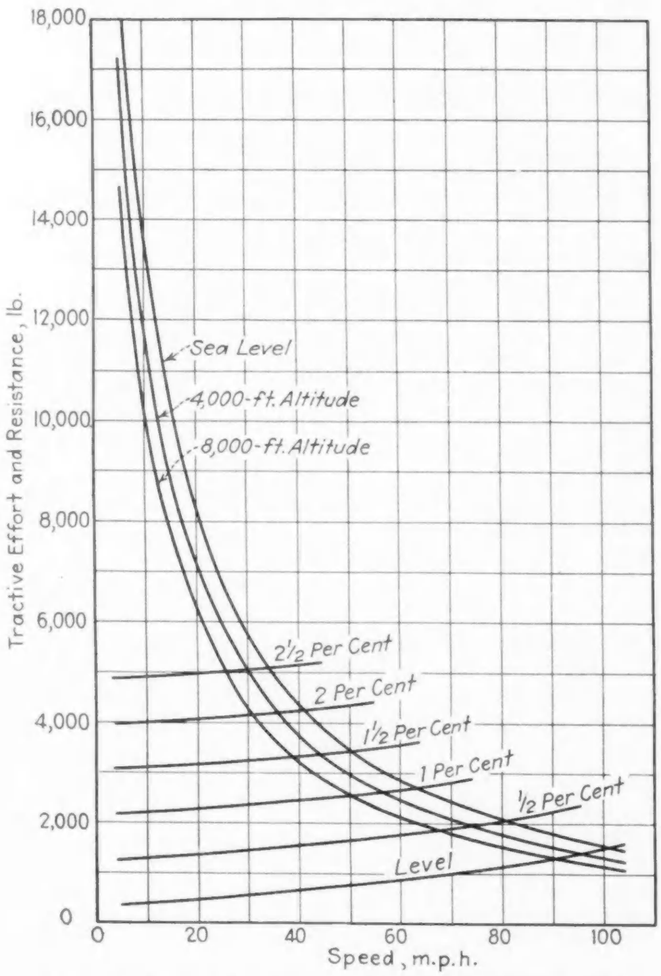

Fig. 10—Curves Showing the Expected Performance of a Three-Car 90.5-Ton High-Speed Articulated Streamlined-Train Having Gas-Electric Drive Rated at 600 Hp. at Sea Level

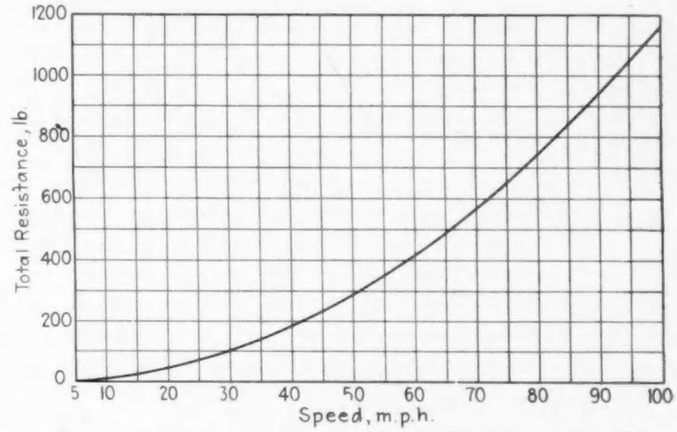

Fig. 11—Curve Showing the Total Resistance in Still Air of a Three-Car High-Speed Diesel Gas-Electric Streamlined-Train Having a Frontal Area of 117 Sq. Ft., the Value of the Coefficient *K* Being 0.001

more space in the car body for its installation. It also requires heavier and more expensive electrical equipment, particularly the generator, because of its lower operating speed. In addition, heavier car-framing and trucks are required to carry it. The cost of these factors must be balanced against the added cost of fuel for the gasoline engine. There is probably no doubt that, for high annual mileages such as proposed for these newer trains where as much as 1000 miles per day may be reached, the Diesel engine will be the cheaper. It can be shown that for low mileages—200 miles per day or more, depending upon the amount of gasoline tax paid—the gasoline engine gives the cheapest overall operation. For intermediate conditions, an analysis of each case is required to determine the most suitable equipment. There is no question but that, for the larger cars and longer daily mileages, the trend is definitely toward the Diesel.

The addition of air conditioning and other such apparently essential refinements have all tended to build up the first cost of these modern train-units. It would seem that the next development should be in the direction of a reduction in the first cost by whatever means may be available, such as less-extreme structures, possible simplification in design and perhaps some means of reducing the cost of the powerplant equipment.

Discussion

Single-Unit-Car Merits Set Forth

—Lowell H. Brown

President, Jaray Streamline Corp. of America

IT seems to me that Mr. Guernsey, in concluding that the trend in motor trains will be away from the streamlined single-unit car and toward streamlined trains with many cars, has missed the main point in the subject at hand. The chief objective, as I see it, is to win back passengers for the railroads and to take railroad passenger-business "out of the red." My studies of this problem over the last few years, and the engineering work which we have done, have led me to the conclusion that the trend will be toward the use of properly designed single-unit cars rather than the use of articulated cars or streamlined trains. Inasmuch as this question has a vital bearing on the attitude of the Society and its

members toward railcars, I will state as briefly as possible the reasons for my belief.

First, it is necessary to analyze what type of service the railroads must offer if they are to compete successfully with highway passenger-carrying vehicles. Unquestionably, such a service must have five characteristics; these are, in the order of their importance:

(1) Fares at least 25 per cent lower than those of highway buses

(2) The maximum frequency of service possible without interfering with freight traffic

(3) The maximum speed of service consistent with safety

(4) The maximum degree of comfort for the passengers

(5) The highest possible degree of safety

Dependability of service is essential and can be assumed to exist in any equipment reaching railroad standards.

To argue whether passengers can be won back from the highways even if these five essentials are met is beside the point. To me, it seems obvious that they can be. It is certainly true that, without meeting these requisites, new passenger-business on any considerable scale can not be expected. It is necessary, therefore, to analyze proposed equipment with these five essentials in mind. To ignore them is to ignore the fundamentals on which any new business in motor trains must be built.

The single-unit car which I am using in the following comparison has not yet been built in America. Many cars approximating it have been built in Europe and have demonstrated their superiority over articulated cars or motor trains by actual service over long periods of time. That a single-unit car with the characteristics mentioned can be built is insured by engineering work which we have completed and which is available for inspection.

In a comparison between the single-unit car, the articulated car and the streamlined train, it will be found that the items involving top speed, comfort and safety, are substantially the same in each. Low cost and frequency of service, therefore, remain to be compared.

First as to cost. Both first cost and operating cost must be considered. The single-unit car will cost under $700 per passenger seat and will operate at less than one-half cent per seat mile, with a crew of three, including 100 per cent amortization in 1,000,000 miles. The three-section articulated-car will cost—without mail and express compartments—$2,200 per passenger seat and will not operate at less than 1 cent per mile per passenger seat, including 100 per cent amortization in 1,000,000 miles. The first cost and operating cost of the multi-car motor-train will be approximately the same as the articulated car per passenger seat, the increase in power-plant capacity due to higher air resistance, and the like, and the heavier construction, just about offsetting the saving due to the larger number of passenger seats. In first cost, therefore, the single-unit car is less than one-third that of the other two types and it will operate at one-half the cost of either of the other two. Per dollar of capital invested per passenger seat, the single-unit car will earn annually 200 per cent more than its competitors, assuming that operating expense and income per passenger seat on the three types are the same.

The single-unit car will afford the railroad the opportunity to offer transportation at rates 25 per cent less than those of highway buses; whereas, the articulated car and the streamlined train will not afford that opportunity.

In any discussion of costs, the cost per passenger mile and the cost per passenger-seat mile should not be confused. In any attempt to compare the three types of equipment on a basis of passenger-mile cost, the single-unit car will show up far better because, due to its small size, it can be used to its maximum efficiency; whereas, the larger units are not adaptable where less than maximum seating capacity is needed. Empty seats in service are far more likely to increase in number as the seating capacity increases, and every empty seat increases the passenger-mile cost. The single-unit car can be used singly or in multiples to conform to traffic requirements, whereas the types with more seating capacity must be run either partly empty or much less frequently.

The second comparison concerns increase in frequency of service. It seems evident that this item will be of paramount importance in winning passengers from the highways. The factors controlling it, from the standpoint of equipment, are as follows: (*a*) seating capacity; (*b*) weight-power ratio; (*c*) first cost per passenger seat; (*d*) controllability in operation.

The seating-capacity factor is obvious. A train seating 300 can not be expected to operate as frequently in any given service as a car seating 60 passengers.

The weight-power ratio affects acceleration and, therefore, is of importance in obtaining frequency of service. The total weight, loaded, of the Budd Zephyr—articulated car—is 240,000 lb. and that of the Jaray Railcoach—single-unit car—is 50,000 lb. The top speed of the two cars is the same. The Budd car is powered with a 660-hp. engine and the Jaray car with a 280-hp. engine. The accelerating ability of the two units, therefore, is as 88 is to 180, the Jaray car having over twice the accelerating rate over the speed range. Naturally, the car with the highest acceleration and deceleration rates is best adapted for increasing frequency of service. Deceleration is the same in both cases.

First-cost comparisons per passenger seat have been mentioned. It is apparent that four single-unit cars costing $200,000 and seating 240 persons are better adapted for frequent service than one three-section articulated car seating 100 persons at the same first cost, or than one streamlined train of five cars seating 240 persons and costing perhaps $250,000.

Controllability in operation is of importance in accomplishing maximum frequency of service. Maximum controllability can not be obtained except with low weight and high power-ratios per passenger seat. The weight of the streamlined multi-car train per passenger seat will exceed 3000 lb., that of the three-section articulated car is approximately 2000 lb. and that of the single-unit car is about 650 lb. Even if power ratios per passenger seat were the same in the three types the single-unit car would operate with a far greater degree of controllability than the heavier types due to its greatly decreased weight per passenger seat. Its more rapid acceleration rates will permit much faster schedules between stations with equal safety. Controllability at high speeds is essential.

From the remarks of Mr. Guernsey it would appear that the single-unit car is not adaptable for use over long mileages and in regions where the distance between stations is very great. This, I believe, is contrary to the facts. The only feature in which the streamline train or articulated car might excel for long-distance travel would be greater comfort due to an observation compartment or a club smoking-compartment, or both. Immediately, when these are supplied, costs must go up accordingly. De luxe travel will probably continue in demand, but we feel that it has no place in the present railroad problem. The single-unit car has every comfort feature of its competitors for long-distance travel, but it is not designed for de luxe service and we do not feel that it should be.

Ice Formation in Aircraft-Engine Carburetors

By H. H. Allen, G. C. Rodgers and D. C. Brooks

National Bureau of Standards

ICE formation in the carburetor must depend on, at least, the factors (*a*) volatility and heat of vaporization of the fuel; (*b*) mixture ratio; (*c*) humidity, pressure, and the temperature of the intake air; and (*d*) heat transfer between the carburetor and its surroundings, especially the engine, according to the authors.

Small-scale and full-scale tests were made, descriptions of the seven fuels used and of the testing apparatus being given. The procedures for both sets of tests are outlined and the results are analyzed. Other subjects treated are the heat necessary to melt ice, and correlation with the A.S.T.M. distillation. Five conclusions are stated.

Appendix 1 refers to calculation of the relation between intake and mixture temperatures when ice formation occurs. Appendix 2 treats of the construction of equilibrium-air-distillation curves for a series of supplied mixture ratios. Appendix 3 is concerned with engine operation near the danger zone and definition of border conditions.

ENGINE stoppage caused by formation of ice in the induction system, particularly in the carburetor, has long been recognized as an occasional cause of airplane disasters[1]. More recently, it has caused trouble in automobiles equipped with unconventional carburetors. As this phenomenon occurs only within rather narrow limits of atmospheric conditions, and only with the more volatile fuels or rich mixtures, it has not hitherto been intensively investigated[2]. In December, 1932, the National Bureau of Standards commenced a research on this subject, sponsored by the Cooperative Fuel Research Steering Committee and made possible by a contribution to this Committee from the Phillips Petroleum Co.

To have ice formation, it is apparent that we must have a source of water and a source of cooling to 0 deg. cent. or lower. The source of water is obviously atmospheric humidity; that of the cooling is the evaporation of the fuel. A brief consideration shows that ice cannot form unless the mixture temperature is below both the dewpoint and the freezing point. In consequence, ice formation in the carburetor must depend on at least the following factors: (*a*) volatility and heat of vaporization of the fuel; (*b*) mixture ratio; (*c*) humidity, pressure, and temperature of the intake air; and (*d*) heat transfer between the carburetor and its surroundings, especially the engine.

The difficulties involved in eliminating or correcting for item (*d*) in full-scale tests made it desirable that the effects of the other factors should be studied before going to engine tests. The initial tests were therefore made on a small-scale setup, consisting essentially of a carburetor and means for conditioning the air and fuel supplied to it. The subsequent engine tests were made in the Altitude Laboratory, using a Curtiss D-12 engine.

Fuels Used.—For the purposes of the tests, seven fuels of the various volatility characteristics shown in Table 1 were used. The A.S.T.M. distillation curves of these fuels are shown in Fig. 1. Fuels 1, 2 and 3 represent the aviation natural-gasoline type. Fuel 1 is a mixture of pentanes and hexanes of volatility beyond the range of commercial gasolines. Fuel 2 represents the extreme volatility in commercial aviation gasolines. Fuel 3 is an admixture with Fuel 2 of a heavier refinery gasoline so that it would comply with the current Army specification which requires that the sum of the 10, 50 and 90-per cent points exceed 564 deg. fahr. (260 deg. cent.). The lettered Fuels *A, B, C* and *D*, are all typical refinery products. Fuel *D* approximately meets the mini-

Table 1—Volatility Characteristics

Fuel	*A*	*B*	*C*	*D*	1	2	3
Reid Vapor Pressure, Lb. per Sq. In.	6.0	6.5	6.5	6.5	7.0	7.0	6.5
Percentage Evaporated	Distillation Temperature, Deg. Cent.						
10	70	70	66	66	61	59	56
50	91	97	96	102	66	73	78
90	109	119	128	135	69	95	128

[This paper was presented at the Annual Meeting of the Society, Detroit, Jan. 23, 1934.]

[1] See N.A.C.A. Technical Note No. 55, March, 1921; Airplane Crashes: Engine Troubles.

[2] See Aeronautical Research Committee (England) R. and M. No. 1549, February, 1933; Fuel Volatility and Carburetor Freezing. See also Air Corps Confidential Report, Serial No. K-57-178, April, 1933; Methods of Heating Carburetor Parts Susceptible to Ice Formation.

mum volatility requirements of fighting-grade aviation-gasoline. Fuels *A, B* and *C,* are all commercial-aviation gasolines of higher volatility than Fuel *D,* differing from one another principally in that their 90-per cent points are successively higher in the order named.

Apparatus.—The tests were made with two separate setups, one small-scale and one full-scale. The small-scale apparatus was designed for two purposes: (*a*) to indicate with a small fuel-consumption the best procedure to follow in the subsequent engine tests, and (*b*) to obtain results in the absence of large amounts of added heat which might otherwise mask some of the effects produced.

The small-scale apparatus is shown in a diagrammatic sketch, Fig. 2, and in two photographs, Figs. 3 and 4. This apparatus consists essentially of a system of two parallel pipes through which conditioned air is inducted from a common source, flow being maintained by an exhauster fan located downstream from the parallel pipes. In the upper pipe a psychrometer is located and in the lower a carburetor venturi, in the throat of which is a jet supplied with gasoline from a metering orifice. The carburetor and float are of conventional design, the rate of fuel supply being controlled by a needle valve. Gasoline is supplied to the carburetor from a pipette of known volume shown in Fig. 3 at the extreme left. Appropriately located valves permit the control of both the volume and the pressure of the air flowing through either pipe, each independently of the other. Pressures are measured by means of manometers shown at the right in Fig. 3. Fig. 2 shows the disposition of the thermocouples in the system, potentials being measured by means of the semi-precision potentiometer shown in both Fig. 3 and Fig. 4.

Starting from right to left in the diagram, Fig. 2, the thermocouples in the air passage are placed to indicate the

[3] See *Journal of the Washington Academy of Science*, Vol. 23, No. 3, March 15, 1933, pp. 121-134; Some Improvements in Psychrometry.

[4] See *Aeronautical Engineering (Transactions of the American Society of Mechanical Engineers)*, Vol. 4, No. 2, April-June, 1932, pp. 53-60; Altitude Laboratory Tests of Aircraft Engines.

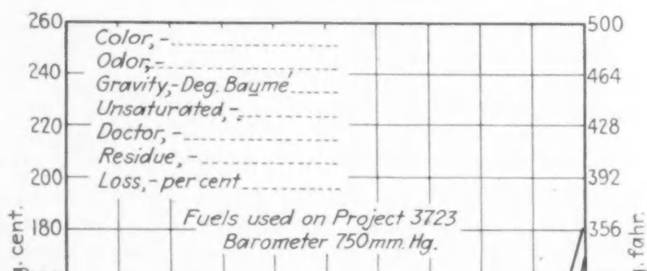

Fig. 1—A.S.T.M. Distillation Curves of the Seven Fuels Used

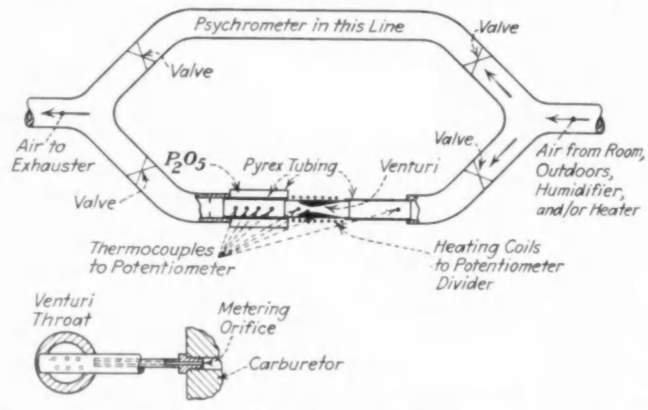

Fig. 2—Schematic Layout of the Small-Scale Apparatus

temperatures of the air entering the carburetor, of the venturi, of the butterfly—kept wide open throughout the tests—and of the mixture at four places downstream from the jet. In addition, another couple was installed near the outer periphery of the venturi shell, and inside the heating coil which surrounded it. As indicated, the downstream pyrex tubing was double, the annular space containing phosphorous pentoxide to insure dryness so that the formation of ice on the inside wall of the venturi might not be obscured by frosting. All of the air drawn through either pipe by the Nash exhauster was metered through sharp-edged orifices, one in each pipe, the pressure drop across each being indicated on the inclined manometers, shown best in Fig. 3. Each orifice was calibrated in place against a venturi of known dimensions and characteristics. Humidity could be increased to any desired amount by steam supplied by the generator shown at the lower right in Fig. 4. The rate of electrical input to this generator—and, consequently, the rate of moisture output—was manually controlled. The psychrometer was an improved type which has been elsewhere described[3]. The electromotive force across the terminals of the heating coil surrounding the carburetor venturi was controlled by means of a lamp-bank connected in series-parallel with the 110-volt source. In the small-scale tests, all of the fuel inducted through the system was rejected unburned.

The large-scale tests were conducted in the Altitude Laboratory using a Curtiss D-12 aviation engine. Means were provided for withdrawing a sample of the air supplied to the carburetor, passing this air through a psychrometer and then rejecting the sample. Provision was made for injecting steam in any desired amount into the air horn of the induction system. Each of the four carburetor venturis of the two dual carburetors was wound with a resistance coil, one end of which was grounded to the engine, the other end being connected to a 110-volt source. A lamp-bank was connected in series with the resistance coils, which were connected in parallel. In all other respects the apparatus used was as is described elsewhere[4].

Small-Scale Test Procedure.—In a large number of the small-scale tests the experimentation was carried on in the winter at night to obtain as low temperatures as were available. The procedure was as follows: Testing was commenced while the humidity and temperature were the same as those of the outside air, to obtain which the room in which the apparatus was contained was opened to the outside atmosphere. Thus, the fuel, venturi and all parts of the

apparatus, approximated the temperature of the entering air. The carburetor needle-valve was set full rich, so that the pipette from which fuel was supplied would empty in minimum time for a given airflow.

Readings of all thermocouples were taken under these conditions, and it was noted whether or not ice formed on the venturi. If it did not, the humidity of the entering air was increased until freezing of water on the venturi walls was observed. The temperature of the entering air was then increased until this ice disappeared, when the temperatures were again recorded. The air temperature was then allowed to decrease until ice re-formed on the venturi and the temperatures were measured, thus obtaining a check determination.

Maintaining constant air-temperature, heat was applied to the heating coil surrounding the venturi until the ice melted, and ice was then allowed to re-form by cutting off the external heat-supply, observations of all temperatures being made under both conditions. Both of the procedures indicated above were repeated with successively leaner mixtures until no ice would form on the venturi. Appropriate determinations of pressures were made for every condition. All of this procedure was carried out both at pressures corresponding approximately to sea-level and to 15,000-ft. altitude.

As some of the experimentation was done in hot weather, artificial refrigeration of the supplied air was necessary. In this case, the gasoline supply and a coiled length of the supply pipe were maintained near 0 deg. cent. by immersion near the carburetor in an ice bath. Due to the fact that the refrigeration available was scarcely more than requisite, the procedure of heating the air supply following formation of ice on the venturi was dispensed with.

Results of Small-Scale Experiments

In Fig. 5 are shown the results of observations for Fuels 1, 2 and 3, and Fuels *A*, *B* and *D*, for those conditions only when freezing occurred in the carburetor. The plot shows the mean curve through the observed results, the ordinates being the temperature of the venturi at the time of the observation, and the abscissas being the pressure of water vapor in millimeters of mercury. Each point on the upper curve shows also the dewpoint corresponding to the air humidity. It is readily seen that there is a very considerable spreading of the observed points above and below the mean curve; but it seemed logical to assume, in drawing the curve, that it would be roughly parallel to the dewpoint curve. Aside from possible errors of observation, the points above this line represent, for the most part, cases in which frost or ice was not generally distributed over the surface of the venturi but was located at a particular point, most often adjacent to the jet on the upstream side. These points represent either the cases where the least-volatile fuels were used, or those cases in which air temperature and humidity, and fuel volatility, combined to cause "threshold" conditions. In addition, even when the venturi temperature was above freezing or above the dewpoint curve, other points in the system were at a temperature below freezing and below the dewpoint. On the other hand, the points which lie farthest below the mean line are, for the most part, cases in which the most-volatile fuels were used, where there was freezing of the whole surface of the venturi, and where the rate of extraction of heat from the air was the most rapid. It is probable, in view of these facts, that the venturi temperatures shown were lower than those at which freezing first occurred, and the

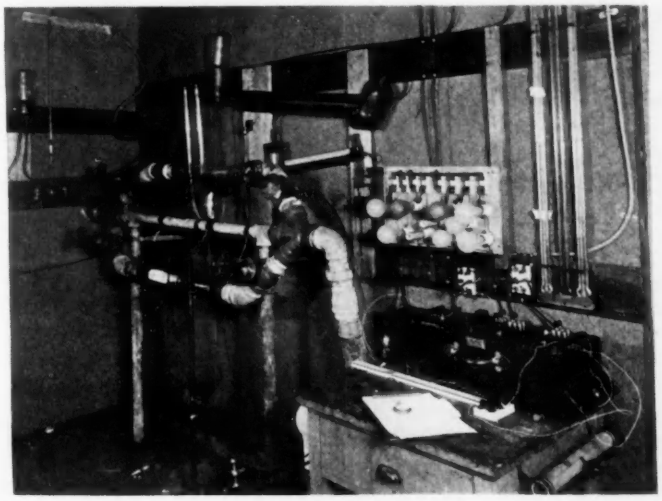

Fig. 3—View of the Testing Apparatus

rate of change of venturi temperature was so rapid that this fact, while known, could not be obviated. The curves show that, at any humidity, freezing is probable when the venturi temperature is about 4 centigrade degrees below the dewpoint. This relation served as a valuable test-index and guide in the large-scale experiments.

In Fig. 6 are shown curves similar to those in Fig. 5, except that the points here represent observations taken at the time when ice disappeared entirely from the venturi and/or the jet, following application of external heat to the venturi, or increase in temperature of the entering air. For reasons similar to those already discussed, there is considerable scattering of points about the line representing their mean. In general the curve representing the data approximates the dewpoint curve.

Fig. 7 shows the relation between supplied fuel-air ratio and the difference in temperature given by a thermocouple in the airstream ahead of the venturi and that in the venturi throat and caused by the evaporation of some portion of the fuel supplied. The mean curves are given for all of the observations for each of the fuels, at the point at which freezing occurs. The scattering of the points is so great in some cases that too much reliance should not be placed upon the curves, but it is safe to say that the relative order of the

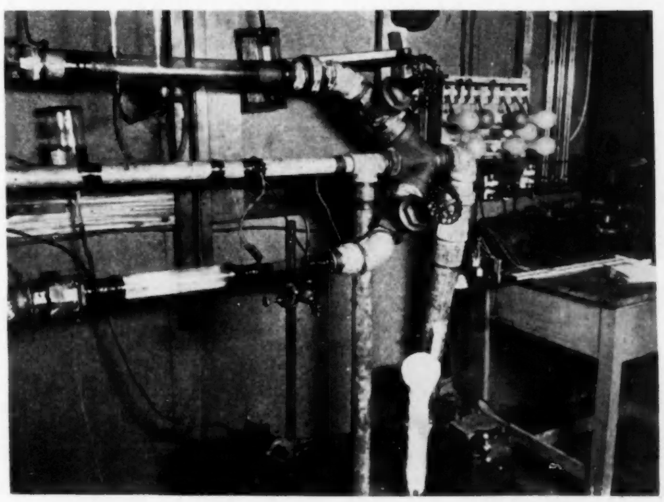

Fig. 4—Another View of the Testing Apparatus

fuels is established. It will be noted that, as would be anticipated, the temperature drop increases with increasing richness of supplied mixture ratio, and that the temperature drop increases for any given supplied mixture ratio as the volatility of the fuel increases. Fig. 8 shows the relation between venturi temperature and the rise in temperature of the entering air, above that at which ice originally formed, required to melt the ice from the venturi.

Analysis of Small-Scale Experimental Results

To this point this paper has described the apparatus used and the results obtained. An attempt was next made to correlate the results with A.S.T.M. distillation-characteristics of the fuels used. To do this it was necessary to formulate a basis by which the temperature drops, for the various fuels, might be calculated for comparison with those observed. A general equation is given below, in terms of the quantities measured in the experiments, by the use of which the temperature drops may be calculated.

$$T_m = \frac{AT_i + C + D - FL_g}{B} \qquad (1)$$

where

T_m = resultant mixture temperature
T_i = temperature of inducted air and gasoline
F = fraction of gasoline vaporized
L_g = latent heat of vaporization of gasoline
AT_i = Σ terms proportional to the heat content of constituents of the mixture at entering temperature, T_i
B = Σ terms proportional to the specific heats of the constituents at temperature T_m
C = Σ terms proportional to the heat absorbed in condensing and freezing all the water vapor that would be condensed at temperature T_m
D = Σ terms proportional to the gain in heat from outside sources.

The calculated temperature drop would then be:

$$\Delta T = T_i - T_m \qquad (2)$$

The variables in this equation, as has been indicated, are all quantities measured in the experiments, or those readily deducible therefrom, except the term F, the fraction of the fuel vaporized. For any desired temperature and known supplied mixture ratio, this fraction may be obtained by the

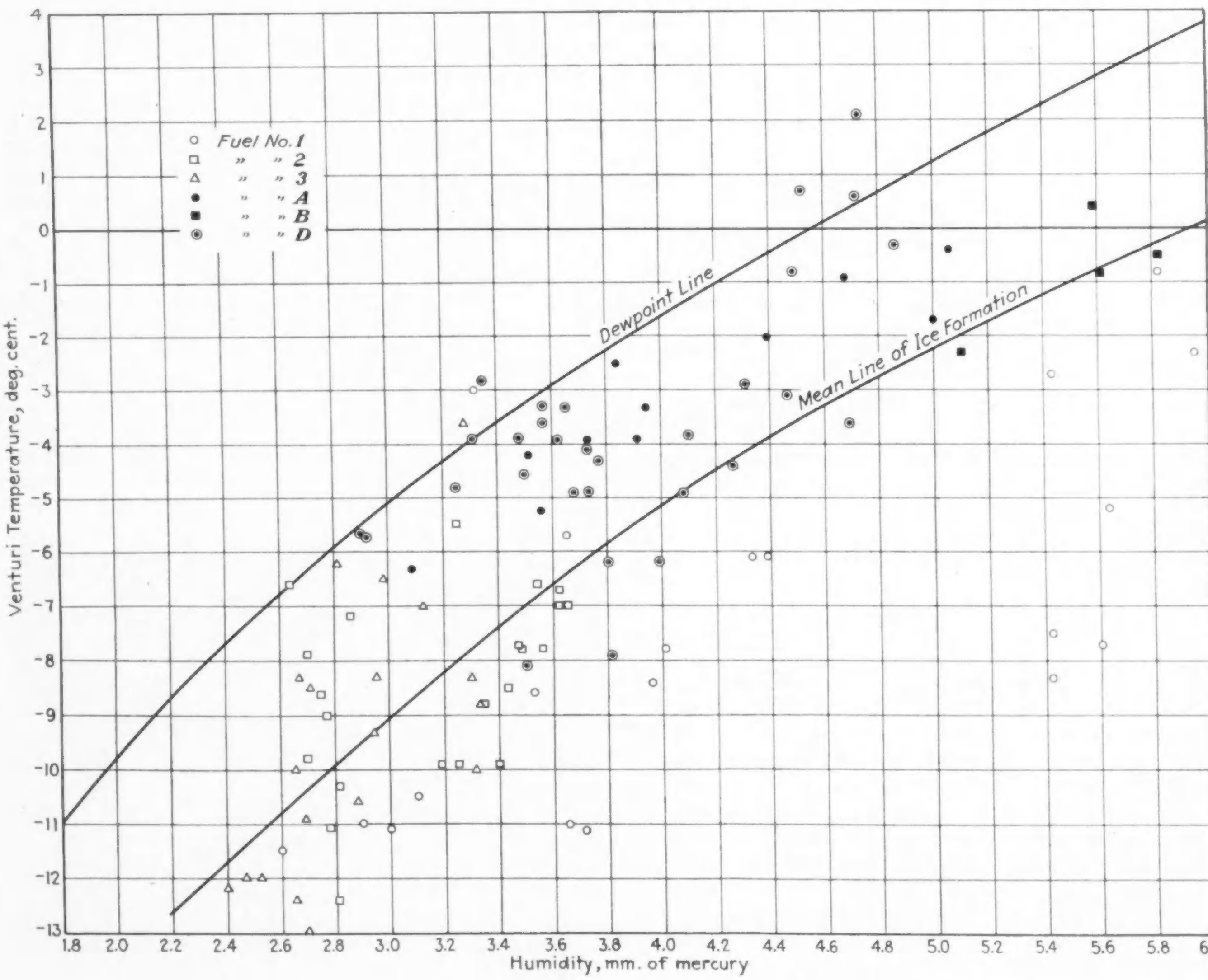

Fig. 5—Conditions under which Ice Reappears following Heating of the Entering Air or of the Venturi

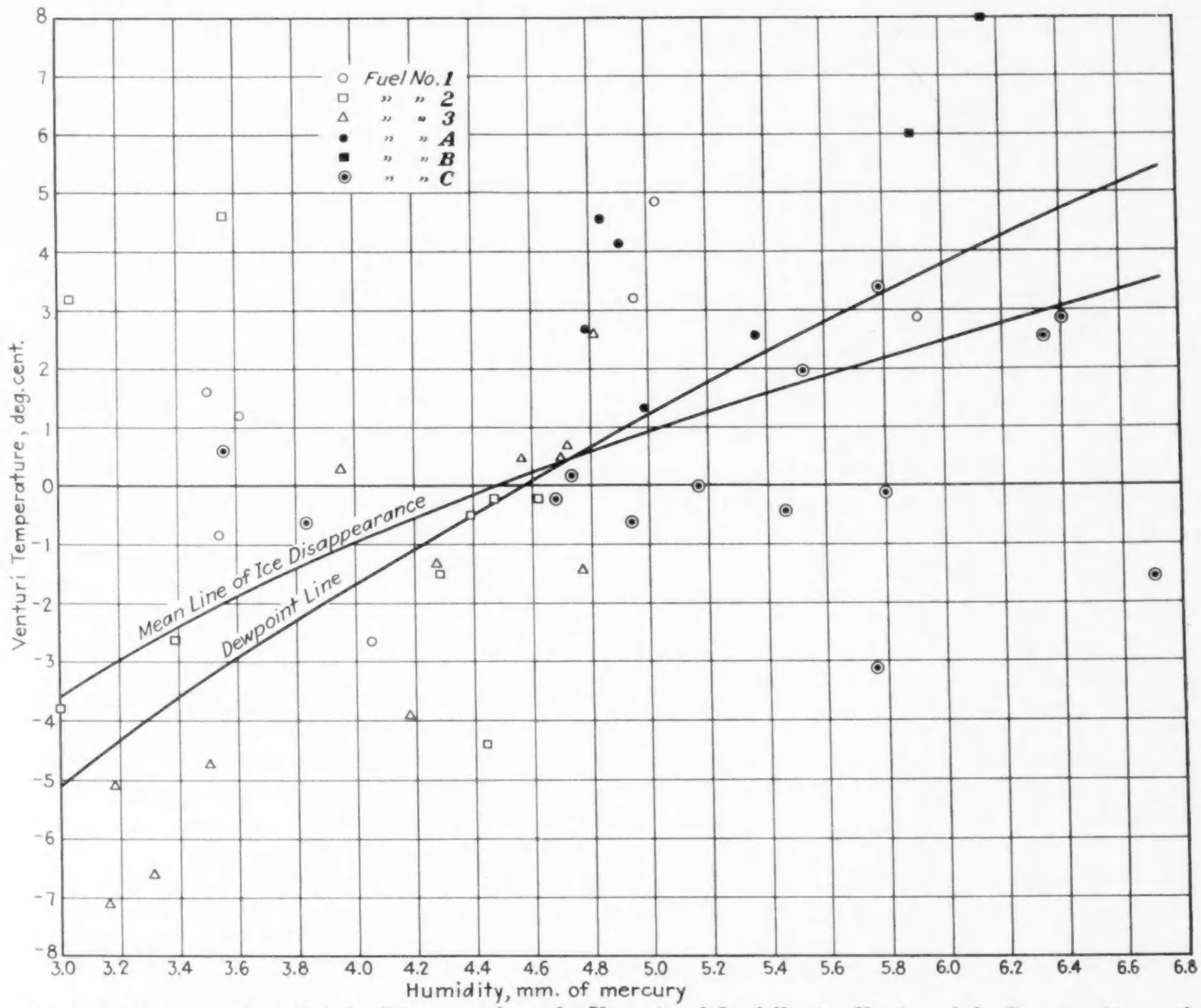

Fig. 6—Conditions under which Ice Disappears from the Venturi and Jet following Heating of the Entering Air or of the Venturi

use of the equilibrium-air-distillation charts, examples for Fuels 1, 3 and *D*, being exhibited in Figs. 9, 10 and 11. These charts were constructed in accordance with a method described elsewhere[5], and similar charts can be constructed for any fuel if the A.S.T.M. distillation-data for it are available.

The derivation of the formula expressed in general terms in Equation (1) is discussed at length in Appendix 1, which also includes certain deductions following therefrom.

For the mixture ratios within the service range there is reasonable agreement between the calculated temperature drops and those observed, if the heat absorbed by condensation and freezing of the moisture be neglected. For mixture ratios leaner than the service range calculated, drops are much less than those observed even when the heat of condensation of moisture is neglected.

Concerning the agreement between observed temperature-drops and those calculated neglecting the condensation term in the equation, several lines of evidence indicate that supercooling of the moisture occurs, the effect of which is to allow at least a part of the moisture to condense at a point beyond the range of the thermocouples. For example, the couples indicate a temperature lower than that calculated. In the service range of mixture ratios, the observed temperature drops lie between the values calculated from the formula with all its terms and the values calculated omitting the condensation term, and somewhat closer to the latter, further tending to substantiate the idea that supercooling occurs. Other evidence is that some of the downstream thermocouples show distinctly higher temperatures than those next higher upstream, which can not be accounted for on the basis of radiation, the couples being but 4 or 5 cm. apart and the air velocities being 60 to 80 cm. per sec., so that the temperature changes would have to occur in 0.05 to 0.08 sec.

The reason why the agreement between calculated and observed results breaks down so badly for mixture ratios leaner than the service range is not apparent. Many hypotheses have been advanced, none of which is satisfactory.

Full-Scale Test-Procedure

All tests on the Curtiss D-12 aircraft engine in the Altitude Laboratory were made at full throttle at 2000 r.p.m. The procedure, after a period of warming up to equilibrium conditions in every case, was to select an air temperature and humidity which, with the leanest mixture ratio on which the engine would operate evenly, would give a venturi temperature somewhat above the line representing the mean of the

[5] See S.A.E. JOURNAL, October, 1929, pp. 345-357; Present Status of Equilibrium-Volatility Work at the Bureau of Standards, by O. C. Bridgeman.

data for the small-scale results, Fig. 5. Observations were taken at this mixture ratio and at successively richer mixture ratios either until freezing occurred or until it was apparent that it would not occur even at full rich. In the latter event, either the humidity was increased or the air temperature decreased until freezing occurred.

The criterion for determining when ice was being formed in the carburetor was a decided and sustained—or increasing—loss of power, which loss could be restored by application of heat to the carburetor venturis. This criterion was dependable, as the loss in power for the sea-level runs was never less than 15 per cent and rapid engine failure would certainly have resulted, in some instances, had the remedial step indicated not been taken. The loss in power in the tests at 15,000-ft. altitude ranged from 15 to 30 per cent. In all cases where circumstances permitted, repeat runs were made.

Results of Engine Tests

The results of the engine tests on the various fuels are plotted in Fig. 12, the mean line representing the relation between carburetor-venturi temperature and humidity at which ice formed to such an extent as to cause faltering in engine operation. The mean line for ice formation for the small-scale tests, which is 1.5 to 2.0 centigrade degrees higher, is also plotted for comparison. It is noted that the criterion in the latter case was visual, and observations were taken at the earliest indication of the formation of ice, in contrast to the described criterion for the engine tests. This, in addition to the fact that ice may have formed at places other than immediately at the point in the carburetor venturis at which the thermocouples were located, probably accounts for the difference between the mean lines for ice formation in the tests, small-scale and full-scale.

As a consequence of the apparent approximate agreement indicated above, it can be legitimately assumed that the method developed for forecasting ice formation in the small-scale tests is applicable to engine operation. It thus becomes possible to forecast ice formation in service, knowing the fuel volatility-characteristics, the supplied air-fuel ratio, the

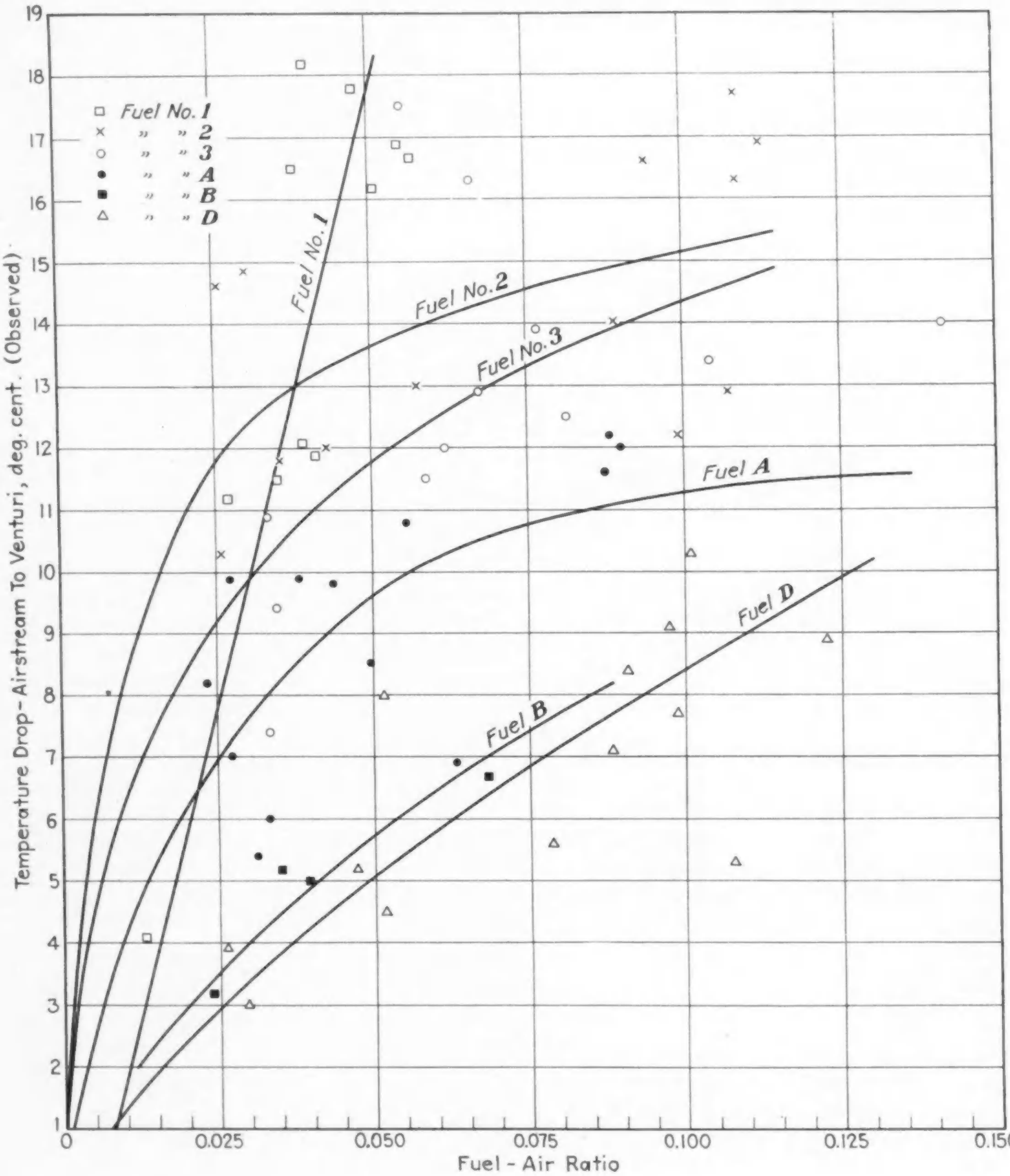

Fig. 7—Relation between Supplied Fuel-Air Ratio and the Difference in Temperature Given by a Thermocouple in the Airstream Ahead of the Venturi and That in the Venturi Throat Caused by the Evaporation of Some Portion of the Fuel Supplied

atmospheric conditions, and a factor denoting the amount of carburetor heating for the engine in question.

Heat Necessary to Melt Ice

In the small-scale apparatus the quantity of electrical energy necessary to melt the ice on the venturi lay between the limits, generally, of 8 to 50 watts, depending upon the temperature of entering air, humidity and fuel volatility. The upper limit, 50 watts, was sufficient to melt the ice from the venturi under the worst conditions; while the lower limit, 8 watts input, was just about sufficient to maintain temperature equilibrium with a moderate formation of ice on the venturi. An input of 50 watts probably represents an excess over the requirement for the most extreme conditions.

Raising the temperature of the entering air is a much slower method of breaking down ice formation than heating the venturi. Under the worst conditions of ice formation on the venturi it was necessary to raise the air temperature 20 to 25 centigrade degrees above that at which ice would initially form in order to melt the ice. To produce this effect by heating the entering air, about 300 watts energy-input is necessary as compared with 50 watts or less when heat is applied directly to the carburetor venturi.

In the engine tests, energy input to the carburetor venturis necessary to melt the ice formed on them lay between the limits of 500 to 900 watts, the spread being smaller due to the fact that air-fuel ratios did not extend over as wide a range.

The ratio of the fuel consumption in the engine tests to that in the small-scale tests, for the same mixture ratios, exceeded the ratio of the energy input required to melt the ice, in the two cases. About 40 times as much fuel was used in the engine tests at an air-fuel ratio of 19 to 1 and about 60 times as much at 15 to 1, while the energy necessary to melt ice on the venturis in the engine was about 20 times as great for the richer mixture and about 50 times for the leaner. The reason for this difference is, obviously, that the venturis receive heat in considerable quantities from the engine, whereas the heat input from the surroundings to the venturi in the small-scale apparatus is small, although not negligible.

Correlation with the A.S.T.M. Distillation

It has been shown that the ice-forming tendency of a fuel depended on the temperature drop which its evaporation caused at the venturi. It was further shown that this actual drop was related definitely to the drop calculated from the equilibrium-air-distillation curves of the fuel. The problem of a suitable index is consequently resolved into that of correlating theoretical or observed drop with, preferably, some characteristic readily deducible from the A.S.T.M. distillation-curve of the fuel.

In Fig. 13, the observed drop obtained from Fig. 7 for a 12 to 1 air-fuel ratio is plotted successively against various distillation criteria as abscissas. In Case 1 the abscissa is the A.S.T.M. corrected temperature at a percentage evaporated exactly equal to the equilibrium percentage evaporated from an air-fuel ratio of 12 at —10 deg. cent.

The present Army specification, which requires that the sum of the 10, 50, and 90-per cent temperatures shall exceed 564 Fahrenheit degrees—260 centigrade degrees—was tested as a criterion in Case 2, in which the sum of these three temperatures is taken as the abscissa.

[6] See Statistical Methods for Research Workers, by Fisher.

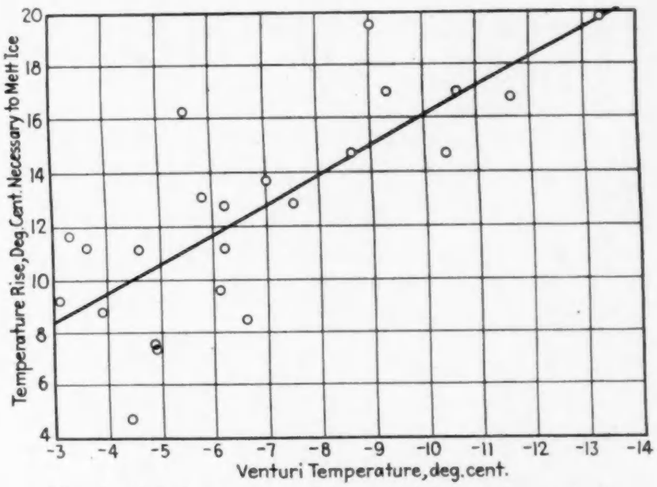

Fig. 8—Relation between Venturi Temperature and the Rise in Temperature of the Entering Air, above That at which Ice Originally Formed, Required to Melt the the Ice from the Venturi

Since the five fuels used in the ice-formation tests were, on the average, 52 per cent evaporated from an air-fuel ratio of 12 at —10 deg. cent., it appeared that the 50 per cent A.S.T.M. temperature, or the sum of the 40, 50 and 60-per cent temperatures, might be a suitable criterion. These constitute Cases 3 and 4 of Fig. 13.

Cases 5 and 9, the last not plotted but included in Table 2, constitute a study of the elements of the Army specification, the abscissas being respectively the sum of 10 and 90-per cent temperatures, the 10-per cent temperature, the sum of the 10 and 50-per cent temperatures, that of the 50 and 90-per cent, and the 90-per cent temperature. In Case 10, abscissas are A.S.T.M. per cent evaporated at 103 deg. cent.

Table 2 gives the correlation[6] of the observed temperature drops with the various abscissas named above. In the second column the correlation coefficient is given. Because but five values of the dependent variable are available. even a high coefficient does not indicate close correlation. Stated in another way, if five points are scattered at random over the same ranges of the variables, the chances are good that a fair correlation will be shown among these random points. The third and fourth columns give average and maximum deviations of the points from linearity, using the least-squares line as a basis in all cases. These deviations give a good practical evaluation of the suitability of the various criteria. The last column gives the chance of obtaining a coefficient as high as that shown in the second column for an equal number of unrelated data. In this sense, "unrelated data" means points scattered at random over the range of variables, as

Table 2—Correlation of the Observed Temperature Drops With the Various Abscissas Named

Case No.	Correlation Coefficient	Average Deviation, Deg. Cent.	Maximum Deviation, Deg. Cent.	Random Probability
1	−0.98	0.5	1.0	1 in 36
2	−0.96	0.7	1.2	1 in 19
3	−0.98	0.4	1.0	1 in 35
4	−0.98	0.4	0.8	1 in 36
5	−0.85	1.2	3.0	1 in 7
6	−0.82	1.8	3.2	1 in 6
7	−0.96	0.7	2.0	1 in 20
8	−0.85	1.5	2.9	1 in 7
9	−0.61	2.3	4.3	1 in 3
10	+0.93	0.9	1.8	1 in 13

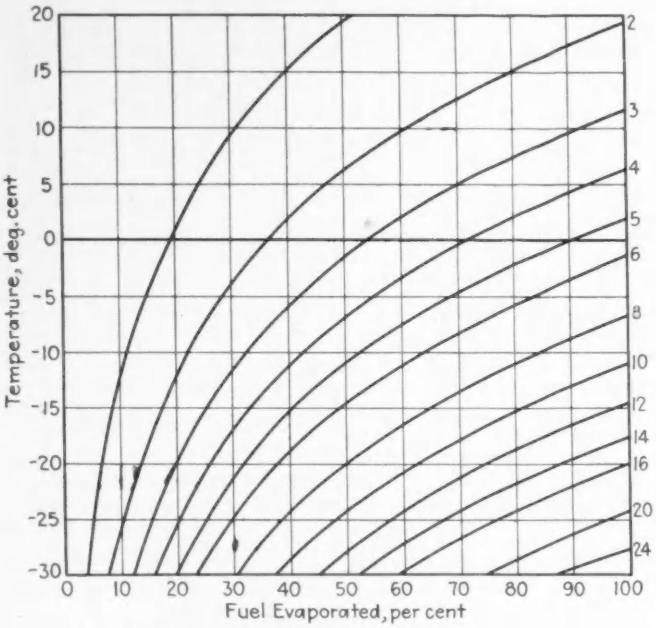

Fig. 9—Equilibrium-Air-Distillation Curves for Various Mixture Ratios, Fuel 1

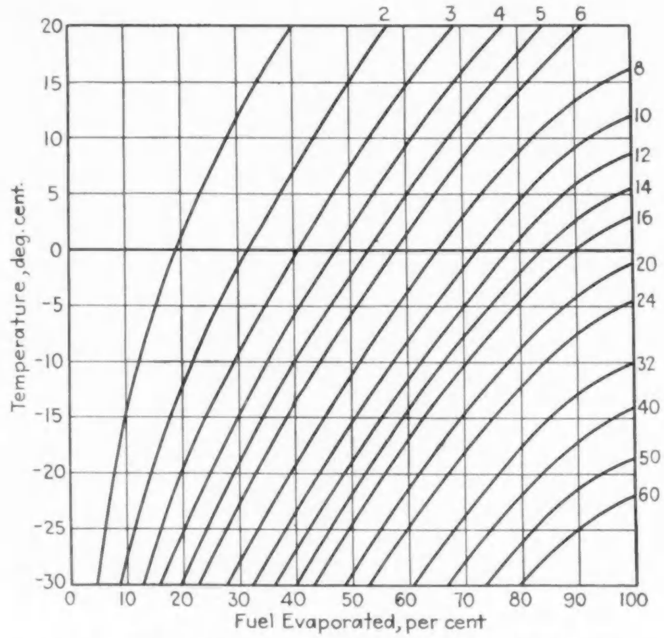

Fig. 10—Equilibrium-Air-Distillation Curves for Various Mixture Ratios, Fuel 3

in the instance just stated. This column gives the rational basis for discriminating between the various suggested criteria.

Although the curves in Fig. 7 from which these correlations are deduced are based on points whose scattering is large, it can be seen from an inspection of Fig. 13 that the correlations would not be materially altered by any change in the curves which did not alter their relative order.

The poorest criterion, on this basis, is obviously Case 9 (90-per cent temperature); the next, Case 6 (10-per cent temperature). These elements of the specification apparently do not contribute individually or collectively (Case 5) to its value; nor do their combinations with the 50-per cent temperature (Cases 7 and 8) improve matters much. By inspection of Table 2 it is evident that there is no single element of the Army specification more significant as a criterion than the 50-per cent point (Case 3), while the sum of the 40, 50 and 60-per cent points (Case 4) is even better. The A.S.T.M. temperature for the percentage evaporated at —10 deg. cent. (Case 1) is about as good as either of the above, but requires the use of the E.A.D. charts and, consequently, is not as handy to use as either of the others.

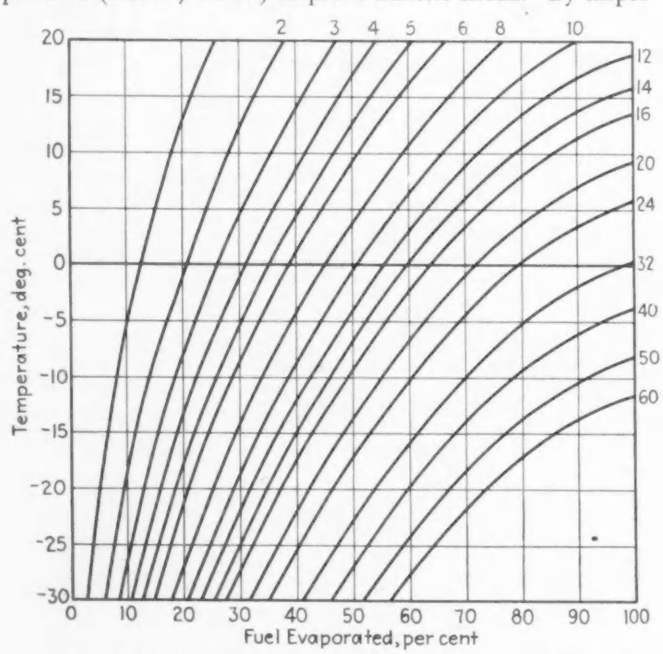

Fig. 11—Equilibrium-Air-Distillation Curves for Various Mixture Ratios, Fuel *D*

In view of the fact that the present Army specification was drafted in the absence of experimental data, it is a surprisingly good criterion of ice formation. However, the present data, together with other considerations, indicate that other bases may be more sound. If further tests were to verify the results of those presented herein, it appears that little difficulty would be experienced in correlating ice-forming tendency with some fuel characteristic readily derived from the A.S.T.M.-distillation curve.

Conclusions

(1) It can be predicted with reasonable certainty that ice will have formed in the induction system in sufficient amounts to effect an appreciable loss in engine power, or that this condition will be impending, at a temperature of the carburetor venturis about 5 centigrade degrees below the dewpoint of the atmosphere, within the range of humidities likely to be encountered in flight, when the venturi temperature is at or below the freezing point.

The findings with the simulated carburetor setup—small-scale tests—approximate those with the engine, the difference being that the mean line of ice formation appears to be at least 1 centigrade degree higher in the former case than in the latter, for reasons indicated in the text. Ice disappeared from the carburetor venturi in the small-scale tests at temperatures quite close to the dewpoint. The temperature at which ice disappeared could not be ascertained definitely in the engine tests.

(2) The small-scale experiments have shown that the venturi temperature in an unheated carburetor can be predicted with considerable accuracy in the service range when

the mixture ratio supplied and the distillation characteristics of the fuel are known. To make similar predictions for the carburetor on an aircraft engine, the heat input to the carburetor must also be known or estimated.

(3) For any particular engine operating under specified atmospheric conditions, the danger of ice formation tends to increase both with increasing richness of the mixture supplied by the carburetor and with increasing volatility of the fuel. As noted in Conclusion (1), venturi temperature and air humidity appear to define the danger zone.

(4) The direct application of heat to control venturi temperature is a much more effective means of preventing ice formation than intake-air heating and requires only a fraction of the energy input. Moreover, direct application of heat appears to have practically no adverse effect on engine power.

(5) The A.S.T.M. corrected 50-per cent temperature is shown to be a much more suitable index than the sum of the 10, 50 and 90-per cent temperature.

Appendix 1

Calculation of the Relation between Intake and Mixture Temperatures When Ice Formation Occurs.—The differences observed between entering-air temperature and minimum temperature in the small-scale tests are best correlated with computed values when the latter are based on the assumption that the water vapor in the entering air is supercooled, and does not begin to condense until the gasoline evaporation has proceeded approximately to equilibrium at the minimum temperature. In calculating the complete relation between entering-air temperature and mixture temperature, however, condensation terms are included. Obviously, if conditions for the formation of ice are suitable only in the supercooled region of minimum temperature, ice cannot form in quantities sufficient to affect power, although it may form to a visible extent. In applying the formulas to the small-scale tests, therefore, it is necessary to assign to the condensation terms the value zero.

In the ensuing discussion it is assumed that the vaporization of the gasoline in the airstream proceeds until the mixture is cooled to the equilibrium-air-distillation temperature for the fraction finally evaporated. It is assumed also that a mass of air, on losing heat by reason of fuel vaporization, cools until it reaches its dewpoint, then coincidentally cools and deposits moisture, remaining saturated the while, until it reaches 0 deg. cent. At this point the condensate, if any, is assumed to freeze, and additional moisture deposited as the air is cooled to its final temperature is assumed to precipitate as ice.

With these assumptions, the relation between intake and

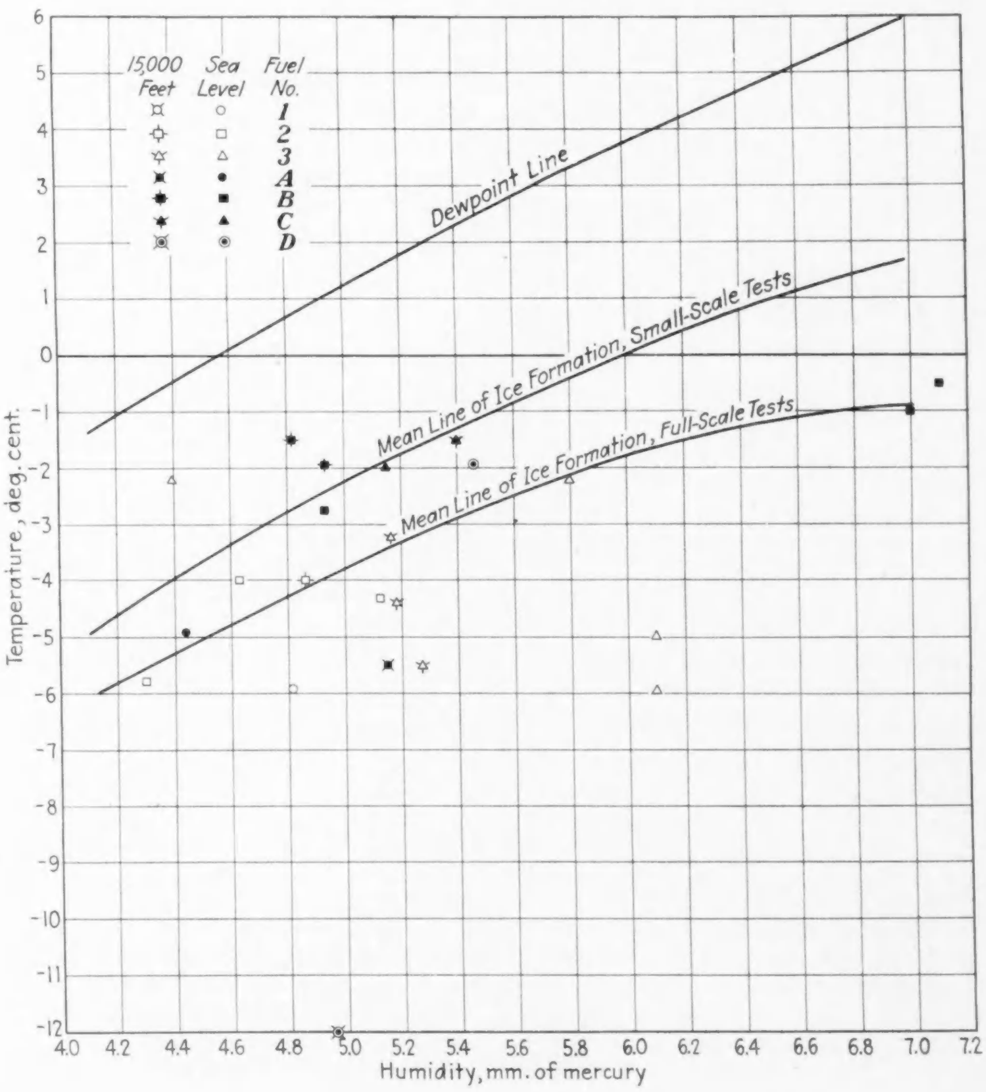

Fig. 12—Results of the Engine Tests on the Various Fuels

mixture temperatures is found by equating the heat required for vaporization of the fuel to the heat given off by the cooling of the air and gasoline, and by the condensation and freezing of the moisture. The notation used is as follows:

F = fraction of gasoline vaporized
(85) L_g = latent heat of vaporization[7] of F
T_i = temperature of inducted air and gasoline
T_m = resultant mixture temperature
T_s = dewpoint of intake air
(760) P_t = total pressure
P_i = pressure of water vapor in the intake air
P_m = vapor pressure of ice at T_m (equals the pressure of water vapor in the mixture by assumption)
P_s = vapor pressure of water at T_s
(4.5802) P_o = vapor pressure of water at 0 deg. cent.
(596.4) L_w = latent heat of vaporization of water at 0 deg. cent.
(79.7) L_f = latent heat of fusion of ice at 0 deg. cent.
(0.238) C_a = specific heat of air near 0 deg. cent.
(0.47) C_w = specific heat of water vapor near 0 deg. cent.
(0.504) C_i = specific heat of ice near 0 deg. cent.
(0.61) C_{vg} = specific heat of gasoline vapor[7] near 0 deg. cent.
(0.48) C_{lg} = specific heat of liquid gasoline[7] near 0 deg. cent.
(0.6225) D = specific gravity of water vapor (air = 1)
(12) R = air-gasoline ratio by weight
H = rise of intake-air temperature which would be required to absorb heat which is transferred to the charge from external sources.

Then:

$$FL_g=\left[(RC_a\frac{P_t-DP_i}{P_t}+RC_w\frac{DP_i}{P_t}+C_{lg}+F(C_{vg}-C_{lg})\right]T_i -\left[(RC_a\frac{P_t-DP_i}{P_t}+RC_w\frac{DP_m}{P_t}+RC_i\frac{D(P_i-P_m)}{P_t}+C_{lg} +F(C_{vg}-C_{lg})\right]T_m+R(L_w+L_f)\frac{D(P_i-P_m)}{P_t}+RC_aH \quad (1)$$

and

$$T_i=\frac{FL_g+\left[(RC_a\frac{P_t-DP_i}{P_t}+RC_w\frac{DP_m}{P_t}+RC_i\frac{D(P_i-P_m)}{P_t}+C_{lg}+F(C_{vg}-C_{lg})\right]T_m-R(L_w+L_f)\frac{D(P_i-P_m)}{P_t}-RC_aH}{RC_a\frac{P_t-DP_i}{P_t}+RC_w\frac{DP_i}{P_t}+C_{lg}+F(C_{vg}-C_{lg})} \quad (2)$$

The boundary intake-air temperature, below which ice can form, is obtained from Equation (2) when T_m = 0 deg. cent. and L_f is arbitrarily assigned a value of zero, and

$$T_i=\frac{F_oL_g-RL_w\frac{D(P_i-P_o)}{P_t}-RC_aH}{RC_a\frac{P_t-DP_i}{P_t}+RC_w\frac{DP_i}{P_t}+C_{lg}+F_o(C_{vg}-C_{lg})} \quad (3)$$

where F_o is the fraction of the gasoline vaporized at 0 deg. cent. in equilibrium-air distillation. Since it has been shown in the body of this report that ice does not form unless T_m is approximately equal to T_s — 4, P_i must equal or exceed the vapor pressure of water at 4 deg. cent. The latent heats of vaporization of all gasolines lie close to 85 calories per gram; this value will be used for L_g hereinafter. Substituting in Equation (3) the values given in parentheses at the left on the foregoing list of symbols, and assuming no external heating (H = 0), the maximum intake-air temperature at which ice can form with a given fuel is:

$$T_{i_{max.}}=\frac{24.8\ F_o-2.6}{1+0.038\ F_o}=\frac{24.8\ F_o-2.6}{1.02}=24.3\ F_o-2.5 \quad (4)$$

Equation (4) applies, of course, only for an air-fuel ratio of 12. Obviously, $T_{i_{max.}}$ is the index of the ice-forming tendency of a fuel. Since $T_{i_{max.}}$ is related by Equation (4) to F_o, the latter is also an index. However, the derivation of E.A.D. curves from the A.S.T.M distillation is laborious, even with the aid of Table 3 given in Appendix 2. It has been found that, for aviation fuels, the approximation that

$$F_o=\frac{P_{103}}{100} \quad (5)$$

where P_{103} equals the percentage evaporated at 103 deg. cent. by A.S.T.M. distillation, is sufficiently accurate for ordinary purposes. Equation (5) is for an air-fuel ratio of 12; the temperatures for ratios of interest are:

Air-Fuel Ratio	A.S.T.M. Temperature at Which the Percentage Evaporated Equals the Percentage Evaporated at 0 Deg. Cent. in E.A.D.
8	95
10	99
12	103
16	110

Values obtained by this means show an average error, when compared with values taken from E.A.D. curves, of 3 per cent.

From Equations (4) and (5), the approximate formula

$$\text{Ice-Forming Index} = 0.24\ P_{103}-2.5 \quad (6)$$

is derived. By means of this formula the ice-forming tendency of a fuel, when used in air-fuel ratio of 12, can be had a glance from the A.S.T.M. curve. For other ratios, for each of which the appropriate P should be used, the coefficient of P is as follows:

Air-Fuel Ratio	Coefficient
8	0.34
10	0.29
12	0.24
16	0.19

However, for normal fuels which are not 100 per cent evaporated from an air-fuel ratio of 16 at 0 deg. cent., the index so found varies but little over the foregoing range of mixture ratio.

The maximum air heating required to obviate ice forma-

[7] See Bureau of Standards Miscellaneous Publication No. 97, November, 1929, pp. 34 and 35; Thermal Properties of Petroleum Products.

tion, provided the intake air is not supersaturated, can be obtained also from Equation (4) for an air-fuel ratio of 12:

$$H_{max.} = 24.3\ F_o - 6.5 \qquad (7)$$

In consequence, a fuel which has a value of F_o below 0.267 (26.7 per cent evaporated at 0 deg. cent. in E.A.D.) cannot form ice so long as the intake air is not supersaturated. Only the poorest automobile fuels, however, have this low a volatility. Hence, ice *can* form, in an unheated carburetor, with any aviation fuel under suitable atmospheric conditions.

An even greater danger is operation in supersaturated air. The heating then required is given by the equation

$$H_{max.} = \frac{85\ F_o}{RC_a} : \qquad (8)$$

For a 12 to 1 air-fuel ratio, this is

$$H_{max.} = 29.7\ F_o \qquad (9)$$

Thus, with an unheated carburetor, ice can form with any fuel, if the air is decidedly supersaturated (T_s = 4 deg. cent. or higher).

Equations (2) and (3) can be simplified greatly, inasmuch as several of the terms are relatively negligible. For an air-fuel ratio of 12 and 760 mm. total pressure, Equation (3) becomes

$$T_i = 24.9\ F_o - 1.71\ P_i - 0.84\ H + 7.8 \qquad (10)$$

and Equation (2) reduces to

$$T_i = T_m + 24.7\ F - 1.48\ (P_i - P_m) - 0.83\ H \qquad (11)$$

The error introduced by these approximations is not over 0.1 deg. cent.

Equation (4) is based on the use of a supplied air-fuel ratio of 12. The analogous equation for any air-fuel ratio, R, is

$$T_{i_{max.}} = \frac{F_o L_g - 0.735\ R}{0.239\ R + 0.48 + 0.13\ F_o} \qquad (12)$$

in which F_o is the fraction evaporated at 0 deg. cent. in equilibrium-air distillation from a supplied air-fuel ratio of R, and L_g is the latent heat of vaporization—in calories per gram—of F_o, hereinbefore assumed to be 85.

Equation (1) cannot be solved directly for T_m, since both F and P_m vary with T_m. An indirect solution can be obtained by assuming a series of values of T_m, computing the corresponding values of T_i from Equation (2) and interpolating

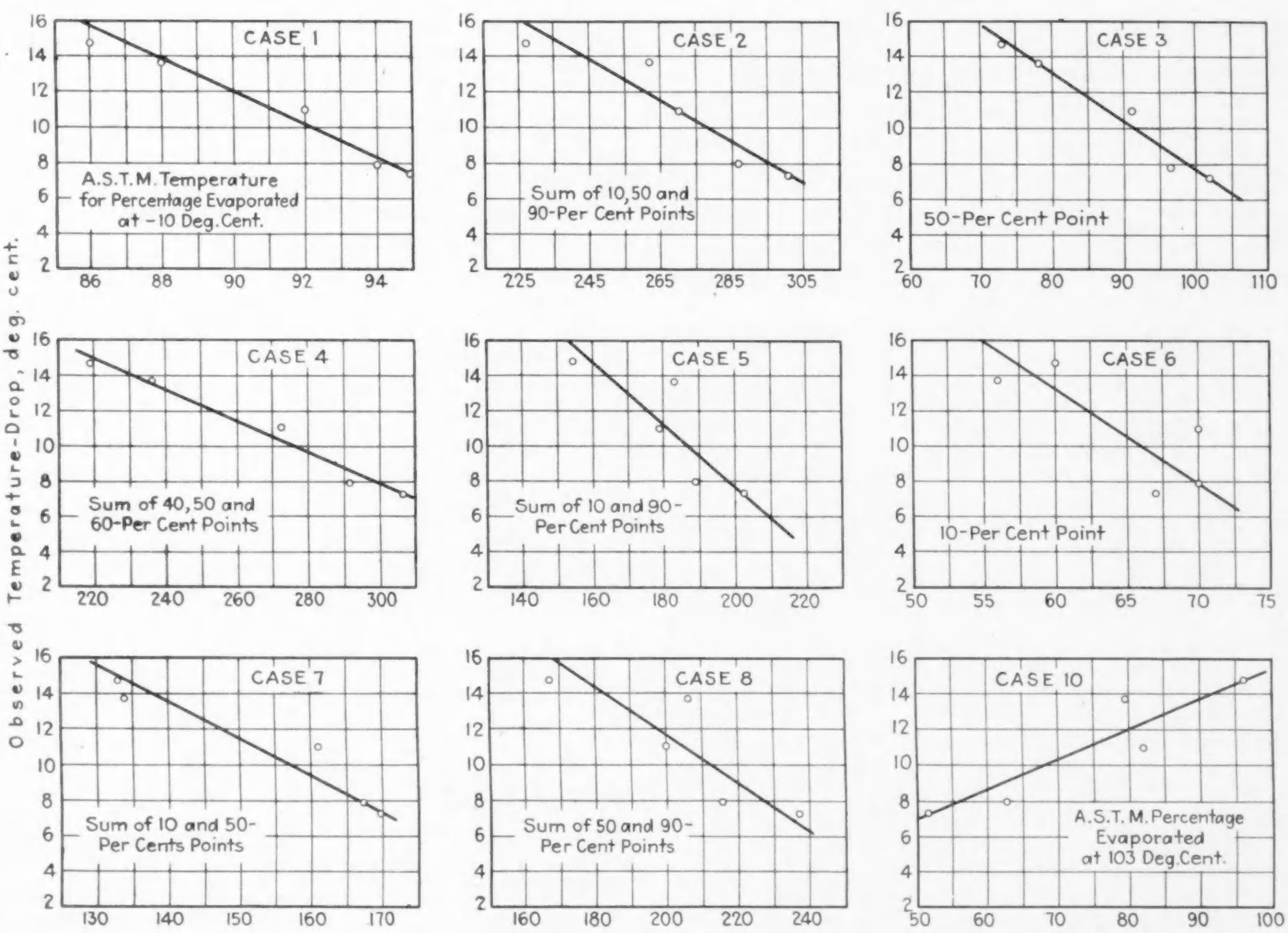

Fig. 13—Observed Drop Obtained from Fig. 7, for a 12 to 1 Air-Fuel Ratio, Plotted Successively Against Various Distillation Criteria as Abscissas

Table 3—Number of Centigrade Degrees To Be Added Algebraically to the Resultant E. A. D. Curve for an Air-Fuel Ratio of 16

Supplied Air-Fuel Ratio	Percentage Evaporated										
	5	10	20	30	40	50	60	70	80	90	100
1	− 4.2	+ 8.9	+22.0	+29.7	+35.1	+39.4	+42.8	+45.7	+48.3	+50.5	+52.5
2	−17.3	− 4.2	+ 8.9	+16.6	+22.0	+26.3	+29.7	+32.6	+35.1	+37.4	+39.4
3	−25.0	−11.9	+ 1.2	+ 8.9	+14.3	+18.6	+22.0	+24.9	+27.5	+29.7	+31.7
4	−30.5	−17.3	− 4.2	+ 3.5	+ 8.9	+13.1	+16.6	+19.5	+22.0	+24.3	+26.3
5	−34.7	−21.6	− 8.5	− 0.8	+ 4.7	+ 8.9	+12.4	+15.3	+17.8	+20.0	+22.0
6	−38.2	−25.0	−11.9	− 4.2	+ 1.2	+ 5.4	+ 8.9	+11.8	+14.3	+16.6	+18.6
8	−43.6	−30.5	−17.3	− 9.7	− 4.2	0.0	+ 3.5	+ 6.4	+ 8.9	+11.1	+13.1
10	−47.8	−34.7	−21.6	−13.9	− 8.5	− 4.2	− 0.8	+ 2.1	+ 4.7	+ 6.9	+ 8.9
12		−38.2	−25.0	−17.3	−11.9	− 7.7	− 4.2	− 1.3	+ 1.2	+ 3.5	+ 5.4
14		−41.1	−27.9	−20.3	−14.8	−10.6	− 7.1	− 4.2	− 1.7	+ 0.5	+ 2.5
16		−43.6	−30.5	−22.8	−17.3	−13.1	− 9.7	− 6.8	− 4.2	− 2.0	0.0
20		−47.8	−34.7	−27.0	−21.6	−17.3	−13.9	−11.0	− 8.5	− 6.2	− 4.2
24			−38.2	−30.5	−25.0	−20.8	−17.3	−14.4	−11.9	− 9.7	− 7.7
28			−41.1	−33.4	−27.9	−23.7	−20.3	−17.3	−14.8	−12.6	−10.6
32			−43.6	−35.9	−30.5	−26.2	−22.8	−19.9	−17.3	−15.1	−13.1
36			−45.8	−38.2	−32.7	−28.5	−25.0	−22.1	−19.6	−17.3	−15.4
40			−47.8	−40.1	−34.7	−30.5	−27.0	−24.1	−21.6	−19.3	−17.3
50				−44.4	−38.9	−34.7	−31.2	−28.3	−25.8	−23.6	−21.6
60				−47.8	−42.4	−38.2	−34.7	−31.8	−29.3	−27.0	−25.0

on a plot of T_i versus T_m. This may be expressed by the following approximate equation:

$$T_{i_{max.}} = \frac{F_e L_0 - 0.735\ R}{0.239\ R + 0.57} \qquad (13)$$

Appendix 2

Construction of Equilibrium-Air-Distillation Curves for a Series of Supplied Mixture Ratios.—For an air-fuel ratio of 16, an equilibrium-air-distillation curve can be constructed by the use of nomograms given by Bridgeman[8]. By adding algebraically amounts also obtained by a nomogram, a family of curves can be obtained for any desired resultant mixture ratios. By then constructing a series of intersecting curves, one for each desired supplied mixture ratio, the percentage evaporated at any temperature can be determined, for any supplied mixture ratio so plotted. By the use of Table 3, which gives the number of centigrade degrees to be added algebraically to the resultant E.A.D. curve for an air-fuel ratio of 16, supplied-mixture-ratio curves may be obtained directly without the necessity for the intermediate steps. This is not only a less laborious method of constructing such curves, but permits greater precision in their use. Figs. 9, 10 and 11 show supplied-mixture-ratio E.A.D. curves for Fuels 1, 3 and *D*, respectively, constructed by the use of Table 3.

[8] See S.A.E. JOURNAL, October, 1929, pp. 345-357; Present Status of Equilibrium-Volatility Work at the Bureau of Standards, by O. C. Bridgeman.

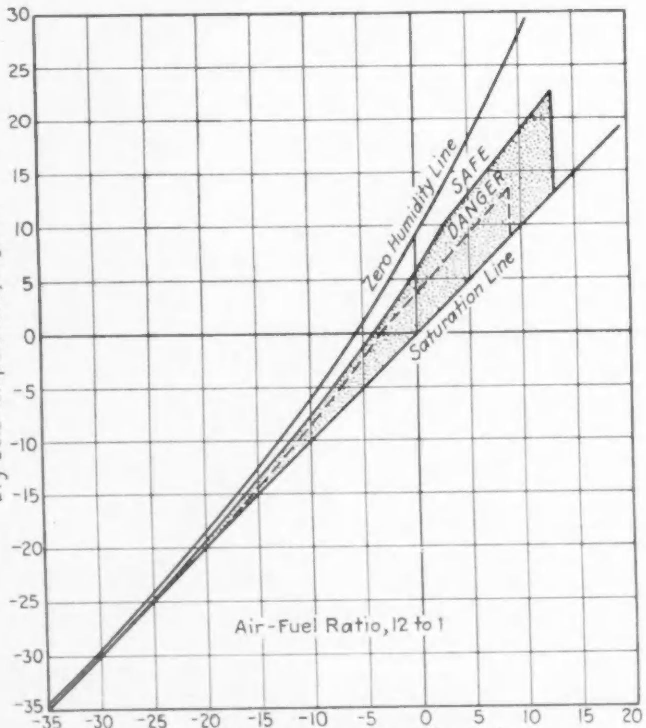

Fig. 14—Air Temperature-Humidity Diagram for Fuel 1

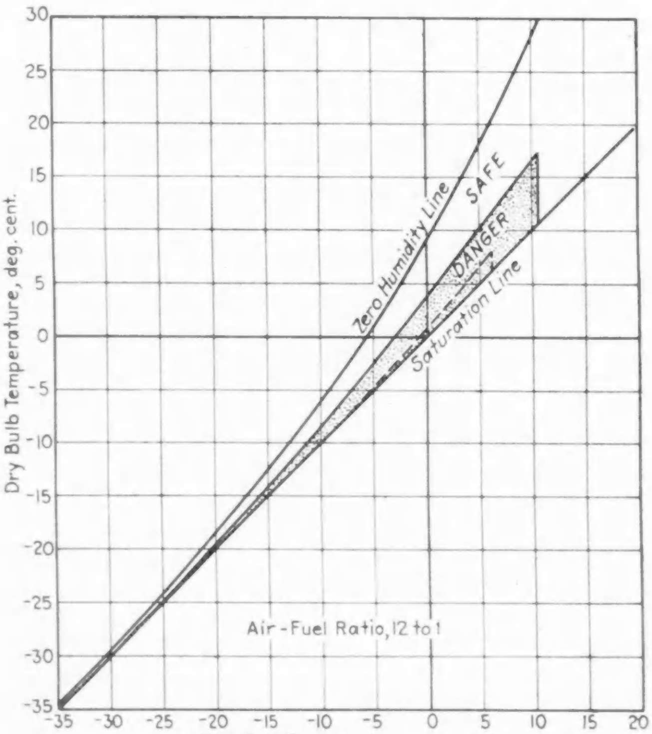

Fig. 15—Air Temperature-Humidity Diagram for Fuel 3

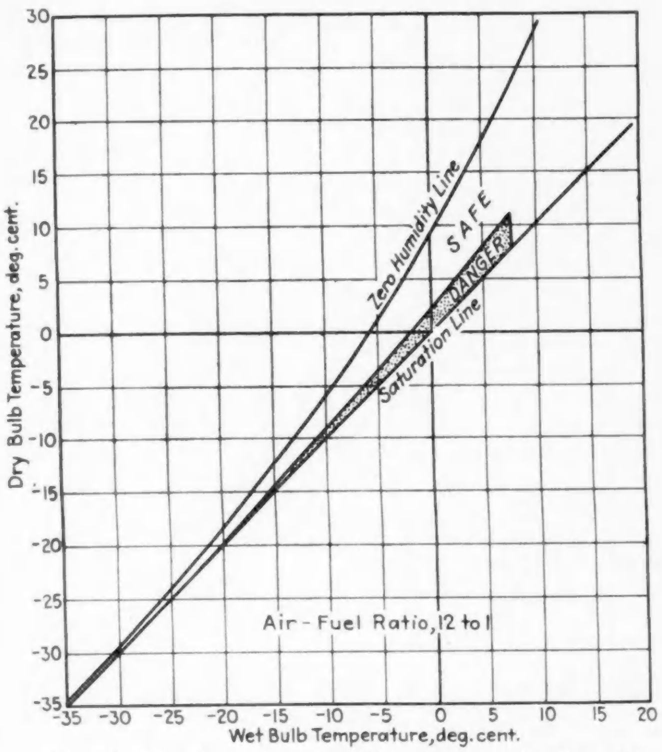

Fig. 16—Air Temperature-Humidity Diagram for Fuel *D*

Appendix 3

Engine Operation Near the Danger Zone—Definition of Border Conditions.—In service, the atmospheric conditions, the supplied air-fuel ratio, and the factor denoting the amount of carburetor heating for the engine in question, under the conditions to be encountered, are knowable in advance. It is possible, in consequence of these tests, to construct for any given unit an air temperature-humidity diagram on which the danger zone of ice formation can be indicated for the unit in question. As humidity, for a given altitude, is a function of wet-bulb and dry-bulb temperatures, the danger zone can be related to these two temperatures. This has been done, for Fuels 1, 3 and *D*, in Figs. 14 to 16.

In Figs. 14 to 16, the curve at the left is the line of zero humidity, and the slanting straight line at the right is the saturation line. Points between these lines represent possible psychrometer readings. The shaded area within these lines represents the region within which ice will form in an unheated carburetor supplying a 12 to 1 air-fuel ratio of the given fuel. The area included between the dotted line and the saturation line represents the danger zone, with an amount of carburetor heating equivalent to heating the intake air 10 centigrade degrees.

At higher altitudes, the horizontal distance between the saturation and zero-humidity lines becomes greater, and the "danger" zone expands slightly more than proportionally, owing to greater vaporization of the fuel. The effect of altitude on the danger of ice formation is slight compared to the effect of differences in fuel volatility, shown in Figs. 14 to 16.

Under most service conditions, operation at altitude will incur less risk of ice formation than operation at sea level, as relative humidity, except within clouds, normally falls off with altitude, throughout the troposphere.

Discussion of G. L. McCain's Paper on Dynamics of the Automobile

As referred to in Mr. McCain's paper, which was published in the S. A. E. Journal, July, 1934, pages 248 to 256 inclusive, "streamlining" is the reshaping of bodies to reduce air resistance at a commercial speed of about 45 m.p.h. The paper presented an analysis of this subject and discussed the effects of a redistribution of passengers and units, together with statements of riding-quality model-test results, comments upon weight distribution, and the inclusion of a bibliography of streamlining.

Exception Taken to Certain Streamlining Statements

—**Lowell H. Brown**
Jaray Streamlining Corp.

I HOPE my comments on Mr. McCain's paper will not be construed as showing any lack of appreciation of his able analysis of the Chrysler Airflow car, but I take exception to certain of Mr. McCain's statements regarding streamlining of the Airflow cars, as follows:

Mr. McCain stated that streamlining of the Airflow cars can be considered as giving them the proper streamline form for a speed of 45 m.p.h. This conception of streamlining is inaccurate. You cannot have a shape efficiently streamlined for a speed of 45 m.p.h. which will not be efficiently streamlined for a speed of 100 m.p.h. or 10 m.p.h.

Mr. McCain says that the more we depart from a true streamline form, that is, a solid body which produces approximately streamline flow, the greater is the energy imparted to overcome eddy currents. Here he completely ignores the fundamental that ground effect demands that the ideal shape be the upper half of the true streamline form.

Mr. McCain states that, theoretically, "streamlining" in a horizontal plane as well as in a vertical plane is necessary. Here he evidently means tapering in a horizontal plane. His statement is misleading. From the text it must be assumed that he means a four-wheeled motor-car. In such a car, tapering in a horizontal plane is relatively unimportant as compared with tapering in a vertical plane.

The most important error in Mr. McCain's paper seems to me to be his conclusions regarding the air coefficients of the various models which were tested. It is unfortunate that he has not accompanied his findings with photographs of the models tested. In my opinion, no reliable results, even of a comparative nature, could have been obtained from the Chrysler tests as conducted.

I base my opinion on the following: The wind tunnel was too small for the models tested and was the wrong shape. Normal ground-effect could not even have been approximated under the conditions which existed. The models were not in the high-pressure zone and were not in the middle of the airstream. The same velocity of the air did not exist in the region of the models as at the point where the velocity of the airstream was measured.

The interruption of the airstream by the models created interruption of the airstream at other points which prevented proper air-flow conditions even for comparative tests. The models were tested on the floor of the tunnel where boundary-layer and static resistances must have been encountered. Moreover, they had to operate with friction bearings of some sort and it would have been impossible to measure the friction resistance due to the bearings employed and the weight of the models on the floor.

It seems obvious to me that results from a test so conducted cannot be relied upon. To publish values for K under such conditions seems highly misleading. Curiously enough, the error seems to be such that the engineering department in this case seems to be less accurate than the sales department in reporting characteristics, a most unusual state of affairs.

The sales department, among many other similar statements, says: "Wind-tunnel tests taught De Soto engineers the ideal shape of an automobile. . . . The result was almost beyond belief." And they announced: "The coming Airflow De Soto will be a car that is *scientifically* streamlined . . . designed as all cars must be in the future." These statements certainly contradict the findings of Mr. McCain, who finds that K for the 1932 sedan is 0.00163 while that for the Airflow sedan is as high as 0.001375. In this case I believe that the advertisers are right and the engineers are wrong.

Checking into some values for K, we find that the streamlined front-engine model of the National Bureau of Standards, tested by Mr. Heald, showed $K = 0.0006$ and that of Professor Lay (Model 28) $K = 0.0008$. We feel that the air resistance of the Airflow model is not over double that of Mr. Heald's model nor is it 80 per cent greater than that of Professor Lay. We also believe that the 1932 sedan reported by Mr. McCain does not have nearly 10 per cent more air resistance than the 1930 sedan tested by Professor Lay. In short, we feel that wind-tunnel tests should be reported for consideration by the members of the S.A.E. or others only when they have been made under conditions where reasonable accuracy can be relied upon.

Differences Between Airship and Automobile Streamlining

—Ralph H. Upson

THE papers on Streamlining by Lowell H. Brown, by Herbert Chase and by G. L. McCain make a particularly good combination. The streamlining work of Jaray, twelve years ago, was a pioneer effort long deserving of recognition, while to the Chrysler Corp. must go much of the credit for the present practical interest in streamlining.

Mr. Jaray's fundamentally sound conceptions bear strong evidence of the undoubted fact that the highest development of the art of streamlining is to be found in lighter-than-air craft; for here one is faced with the problem of streamlining not merely a few square feet, but projected areas up to 10,000 sq. ft., and volumes running 50,000 times greater than that of an automobile. And the principles involved are mainly emphasized, rather than changed, by the size. This is well illustrated by the fact, briefly mentioned in the paper, that effective streamlining does not necessarily depend on having a very long fine shape popularly associated with that of an arrow, or even a cigar. Starting out with such an idea, Count Zeppelin made his early airships of a fineness ratio (length/diameter) approximating 12. As a result of Mr. Jaray's work, this was reduced to about 7. But the development has been carried furthest in this country where, in the Metalclad airship ZMC-2, a fineness ratio of 2.84 was demonstrated to be not merely satisfactory but in many respects unprecedentedly efficient. At the same time it showed effectively for most purposes that a proper choice of general lines and details made unnecessary a fine pointed tail. Similar principles are applicable to automobiles, specially considering that a car designer would be well pleased to achieve a net air-drag one-quarter that of the flat-plate projected-area which, though one-half that of the present average for cars, is still about four times the value expected in a good airship.

Certain important differences must be considered, however. Streamlining an airship is mainly a problem of shaping a given volume; whereas, in an automobile, the accepted requirements of width and height make it mainly a problem of fairing a given frontal projected area, including of course the necessary parasite parts. Another important difference, as mentioned in connection with Jaray's work, is the ground effect. Unfortunately, however, this cannot be entirely disposed of by conventional wind-tunnel methods, but must be studied mainly as a problem in boundary-layer control, a comparatively new phase of aerodynamics largely developed during the last ten years and still being actively pioneered. Finally, the value of streamlining must be judged, not only by the air drag itself, but by comparison with other drains on the power supply.

It is quite true, as brought out by Messrs. Brown and Chase, that a given percentage saving in *air drag* is approximately the same at any speed, but they might have made it clearer that it is far from a constant percentage of *total drag;* and it would be hard to substantiate their claim that streamlining "is still an important factor even at speeds of 30 m.p.h. or lower." Their formula for total power is apparently taken from the old assumption of constant rolling-friction at all speeds. Recent evidence shows that speed is also a considerable factor here, though not to the extent of its effect on air drag. This is well shown in Mr. McCain's final chart as part of the "chassis friction," which, it is understood, includes all losses except air resistance, though labeled as if it were all internal friction. If his air-drag power is scaled up directly from wind-tunnel tests, it is undoubtedly low, but may still be assumed to give a fair picture of the magnitudes involved.

Reading directly from the curves, we see that at 30 m.p.h. the power consumed by air drag is approximately 2 hp., less than one-third of the total power consumed at that speed, or about 2 per cent of the gross brake-horsepower of the engine. On the other hand, at 60 m.p.h., the air-drag power rises to well over one-half of the total consumed; while, at 90 m.p.h., it quite dominates the picture. This is for a car which is obviously more of a stylist's than a streamliner's job, and for that reason is more nearly representative of present-day performance than of possibilities for the future. In other words, by far the greater part of Mr. Jaray's very fair estimate of possible saving is still untouched. Is not the remedy to be found in closer relations between streamliner and stylist?